HQ Air Force Center for
Environmental Excellence

Monitoring and Remediation Optimization System (MAROS)

SOFTWARE

User's Guide

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AFCEE
Monitoring and Remediation Optimization System (MAROS) Software

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List of Acronyms

ACRONYM	DEFINITION
AFCEE	Air Force Center for Environmental Excellence
AR	Area Ratio
ASTM	American Society for Testing and Materials
CERCLA	Comprehensive Environmental Response, Comprehensive and Liability Act
CES	Cost Effective Sampling
COC	Constituent of Concern
CR	Concentration Ratio
CT	Concentration Trend
ERPIMS	Environmental Resources Program Information Management System
LLNL	Lawrence Livermore National Laboratory
LOE	Lines of Evidence
LTM	Long Term Monitoring
MAROS	Monitoring and Remediation Optimization System
MCL	Maximum Concentration Level
NAPL	Non-Aqueous Phase Liquids
ND	Non-Detect
PRG	Preliminary Remediation Goal
RCRA	Risk-based Corrective Action
ROC	Rate of Change
SF	Slope Factor
UST	Underground Storage Tank

INTRODUCTION

The AFCEE Monitoring and Remediation Optimization System (MAROS) Software is a Microsoft Access® database application developed to assist users with groundwater data trend analysis and long term monitoring optimization at contaminated groundwater sites. This program was developed in accordance with the Long-Term Monitoring Optimization Guide Version 1.1 developed by AFCEE. The software uses both primary lines of evidence (parametric and nonparametric trend analysis) developed by Groundwater Services, Inc., as well as allowing users to enter secondary lines of evidence (empirical or modeling results) for the site. These lines of evidence allow recommendations as to future sampling duration, location and density in order to assist users in identifying future compliance monitoring goals for their specific site. This User's Guide will walk the user through several typical uses of the software as well as provide screen-by-screen detailed instructions.

INTENDED USES FOR THE MAROS SOFTWARE

Along with the guidance found in the Long-Term Monitoring Optimization Guide (AFCEE, 1997) you can use the software to answer important compliance monitoring data questions:

- Is the trend in the groundwater site data significant?
- How important is each well in the trend analysis?
- What is the suggested future monitoring well density, sampling frequency and duration?
- What COCs are identified at the site?
- What wells are statistically relevant to the current sampling program?

The MAROS software can be utilized in a step-by-step fashion, with each progressive step along the way yielding information that can be applied to answering site-specific compliance monitoring questions. At each phase in the software, results that are presented are based on increasingly more consolidated data. These data consolidation steps will lead to a higher degree of assumptions being used in order to reach a result or site specific results (Figure 1). The assumptions you make along the way, will affect the outcome of the software tool results. Also, the validity of the results or recommendation will rely on the extent and quality of your data. The data imported into the software must meet minimum data requirements as to the frequency of sampling, duration of the sampling intervals for trend analysis and sampling density for the site as well as the quality of the measurements (decreased amount of false positives/negatives).

- Basic output: 1 page Sampling Plan that is intended to be used as a "strawman" or basis for discussion (not as an authoritative, detailed statistically based product). The user can apply additional tools in MAROS to refine this basic plan. An important premise for the report is knowledge of historical trends for each COC and each well. However, the software is **not** a kriging tool at this time. Sample data reduction and data analysis tools result in summary reports.

Note: For kriging, available software products include: GEOEAS or GEOPack from the U.S. EPA. Also, some commercial software for kriging include "GS+ Geostatistics for the Environmental Sciences", GMS (Groundwater Modeling System), and EarthVision. These software products include variograms and kriging for the purpose of interpolation, but are not specifically geared toward groundwater well network optimization. A higher level of statistical knowledge and background would be required to implement these geostatistical tools.

The AFCEE MAROS Software should be used in Access 97® along with Excel 97® in order to analyze the trends in groundwater data as well as perform statistical optimization of well location, sampling frequency and duration. The software can be used to export data to an Access archive file for future software use. Groundwater data can be imported from Excel or ERPIMS files as well as entered manually.

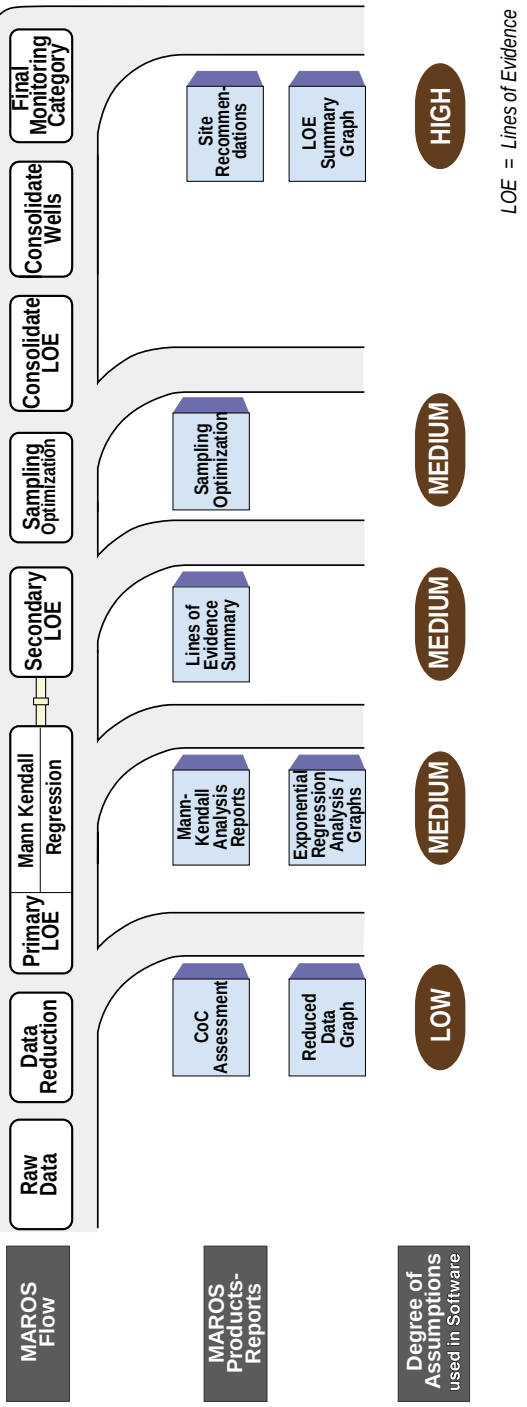


FIGURE 1 MONITORING AND REMEDIATION OPTIMIZATION SYSTEM (MAROS) PROGRAM FLOW

FUNDAMENTALS OF COMPLIANCE MONITORING

Remediation monitoring of affected groundwater is a significant cost driver for future environmental restoration activities. These monitoring systems whether applied for process control, performance measurement or compliance purposes, referred to as long-term monitoring, are dictated by RCRA, CERCLA and UST programs. Although an individual long-term monitoring data point is relatively small, the scale of the required data collection effort and the time commitment makes the cumulative costs very high. Consequently, improving the efficiency of these systems through improved methodology for developing future long-term monitoring plans has the potential for substantial cost savings.

The features available in the MAROS software are designed to optimize a site-specific monitoring program that is currently tracking the occurrence of contaminant migration in groundwater. MAROS is a decision support tool based on statistical methods applied to site-specific data that account for hydrogeologic conditions, groundwater plume stability, and available monitoring data. This process focuses on analyzing relevant current and historical site data and optimizing the current monitoring system in order to efficiently achieve the termination of the monitoring program. For example plumes that appear to be decreasing in extent, based on adequate monitoring data over a several year period, can be analyzed statistically to determine the strength and reliability of the trend. If it can be demonstrated statistically through primary lines of evidence (i.e. Mann-Kendall Analysis and/or Linear Regression Analysis) and/or secondary lines of evidence (modeling or empirical) that the plume is shrinking with a high degree of confidence, then future monitoring can either be suspended or reduced in scope (i.e. from annual monitoring to biennial monitoring).

MAROS has the option to either use simple rules based on trend analysis results and site information or more rigorous statistical methods to determine the minimum number of wells and the minimum sampling frequency and well density required for future compliance monitoring at the site. These preliminary monitoring optimization recommendations will give the user a basis for which to make more cost effective, scientifically based future long-term monitoring decisions. As the monitoring program proceeds, more recent sampling results can be added to historical data to assess the progress of the current monitoring strategy. Then the optimization process can be reviewed and updated periodically using the MAROS guidance recommendations.

QUICK START

Minimum System Requirements

The AFCEE Monitoring and Remediation Optimization System Software runs with Microsoft® Access 97 database software and Microsoft® Excel 97. Operation requires an IBM®-compatible PC with Pentium or later processor. To operate efficiently we recommend that the PC have a minimum of 32 MB RAM (optimal 64 MB RAM), 100 MHz clock speed, and EGA or VGA graphics display. Microsoft Access 97®, Microsoft Excel 97®, plus Windows 95® or later or Windows NT® are required software.

Installation and Start Up

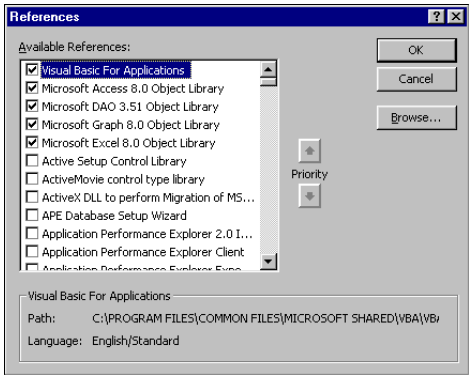
Copy MAROS_SETUP.EXE to your hard drive, then run MAROS_SETUP.EXE either by selecting Run from the File menu in Program Manager or by double-clicking on the file MAROS_SETUP.EXE in File Manager (or Windows 95 Explorer). The installation process creates the C:\AFCEE_MAROS subdirectory on your hard drive, unless you install it elsewhere, and

copies the MAROS files into the new directory. This folder contains five files needed to use the software.

1) AFCEE Monitoring and Remediation Optimization System Software: "afcee_MAROS.mdb"
2) Help file: "afcee_MAROS.hlp"
3) Optimization Excel File: "xlsDelaunay.xls"
4) Trend Visualization File: "xlsLOEresults.xls"
5) MAROS Manual: "afcee_MAROS_Manual.pdf"

To start the software after installation, double click on the "afcee_MAROS.mdb" file or open the file from within Access 97®.

Note: *Although some users are likely to have the complete set of libraries "turned on" to run the program, the following procedure should be applied the* ***first*** *time the software is used.*



1) Start up main software "afcee_MAROS.mdb". The Start up screen will appear. Press "F11" on the keyboard.

2) The Main Access Program will appear. Click on the tab "Modules". Open the Module "A MAROS Initial Start Up References".

3) Go to the Menu Item "Tools…. References…." A pop-up list of items will appear. Choose the following libraries to utilize. Click on the following libraries IF they are not already chosen

Visual Basic for Application; Microsoft Access 8.0 Object Library; Microsoft DAO 3.51 Object Library; Microsoft Graph 8.0 Object Library; Microsoft Excel 8.0 Object Library

Click on "OK" when finished.

4) Exit Access from the Menu Item "File…. Exit"

MAROS SOFTWARE STEP-BY-STEP

MAROS Step-by-step instructions will guide the user through the most commonly used features of the software. Figure 2 directs the user through the complete MAROS program flow which will assist the user in becoming familiar with the use of the software.

How can I import/enter groundwater data into MAROS?

The MAROS Software allows manual data entry or importation of data into the software.

To import data within the software:

1) ***Main Menu:*** From the *Main Menu*, select "Data Management" by clicking on the button next to the label. This will take you to the *Data Management Menu* Screen.

2) ***Data Management Menu:*** From the *Data Management Menu*, select "Import New Data" by clicking on the button next to the label. This will take you to the *Import New Data* Screen.

3) ***Import New Data:*** Choose the type of data import to be performed by clicking on the appropriate button (Excel or ERPIMS). Enter the full file path and filename of the file to import (or click the browse button to find the import file). The Folder and File name you choose will appear in the top two boxes. (See Notes below for ERPIMS and Excel file format/names.) Choose the import option that corresponds to the import data. (Note that the "Import New Data" option will replace the existing data in the database.) Click "Import" to proceed with importing the file to the existing database. (See page 13 of Appendix A.7 for more information).

To enter individual data records manually within the software:

1) *Main Menu:* From the *Main Menu*, select "Data Management" by clicking on the button next to the label. This will take you to the *Data Management Menu* Screen.

2) ***Data Management Menu:*** From the *Data Management Menu*, select "Manual Data Addition" by clicking on the button next to the label. This will take you to the *Manual Data Addition* Screen.

3) ***Manual Data Addition:*** Fill in the appropriate information within each field. Fields such as "Constituent Type" and Constituent have dropdown boxes to assist in data entry. Choose Constituent Type before choosing the Constituent. Review information before adding the record. When all the data is entered, click on the "Add Record" button.

Note: If the result is "ND" then fill in the Detection Limit. (See page 16 of Appendix A.7 for more information).

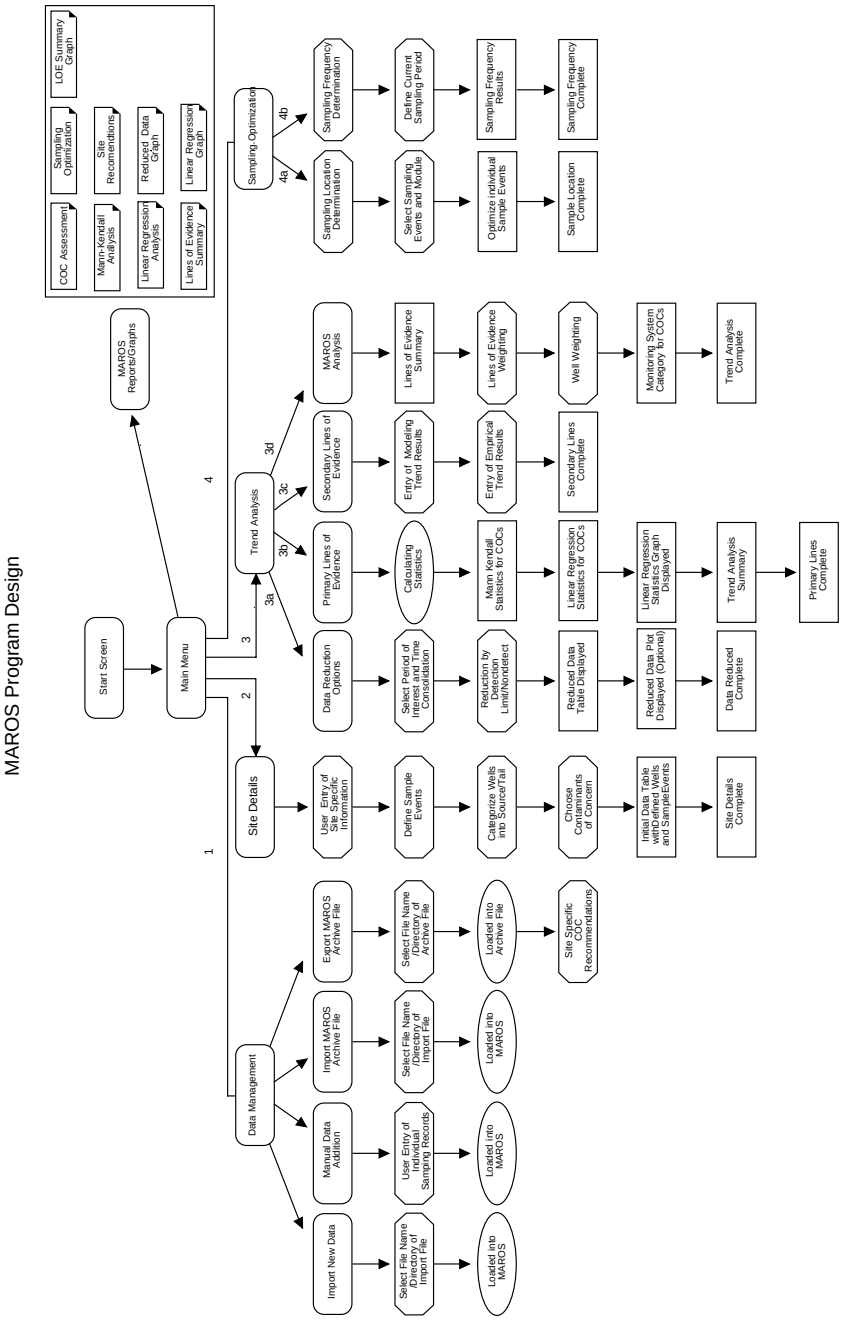


FIGURE 2 MONITORING AND REMEDIATION OPTIMIZATION SYSTEM (MAROS) PROGRAM DESIGN

How will MAROS help perform a trend analysis and give a Site-Specific Recommendation based on groundwater data and site conditions?

The MAROS Tool can generate a summary report for a selected set of data imported by the user. To generate the summary report for the Mann Kendall or Linear Regression Trend Analysis:

1) Follow directions for Importing/Entering Data above.

2) ***Main Menu:*** From the *Main Menu*, select "Site Details" by clicking the button next to the label. This action will take the user to the *Site Information* screen.

3) ***Site Details:*** In each screen select the information that describes the site, click on "Next" to continue to the next screen. First, enter the site details on the *Site Information* screen. Next, define sample events on the *Sample Events* screen. Then select the representative wells in the Source and Tail zones on the *Source/Tail Zone Selection* screen. Continue to the *Constituents of Concern Decision* screen to choose the representative COCs for the site. The next screen, *Initial Data Table* , will show the data to be evaluated. To proceed click "Next". The site details portion of the software is complete.

4) ***Main Menu:*** From the *Main Menu*, select "Trend Analysis" by clicking the button next to the label. This action will take the user to the *Trend Analysis Menu* screen.

5) ***Trend Analysis Menu:*** From the *Trend Analysis Menu*, select "Data Reduction" by clicking the button next to the label. This action will take the user to the *Data Reduction Part 1 of 2* screen.

6) ***Data Reduction:*** In each screen select the information that will define the data you would like to analyze, click "Next" to continue to the next screen. First, enter the period of interest as well as data consolidation options on the *Data Reduction Part 1 of 2* screen. Next, define delimit the data on the *Data Reduction Part 2 of 2* screen. Continue to the *Reduced Data Table* screen to view the results of data consolidation. To proceed click "Next". The data reduction portion of the software is complete.

7) ***Trend Analysis Menu:*** From the *Trend Analysis Menu*, select "Primary Lines of Evidence" by clicking the button next to the label. This action will take the user to the *Mann Kendall Statistics* screen.

8) ***Primary Lines of Evidence:*** In each screen select the information view the information from both the Mann Kendall and Linear Regression Statistical Analyses, click "Next" to continue to the next screen. Results of the Mann Kendall Trend Analysis are shown on the *Mann Kendall Statistics* screen. Next, results of the Linear Regression Trend Analysis are shown on the *Linear Regression Statistics* screen. Continue to the *Linear Regression* screen to view the results in graphical form. Finally a summary of both the Mann Kendall and Linear Regression results are shown on the *Trend Analysis Summary by Well* screen. To proceed click "Next". The Primary Lines of Evidence portion of the software is complete.

9) ***Trend Analysis Menu:*** From the *Trend Analysis Menu*, select "Secondary Lines of Evidence" by clicking the button next to the label. This action will take the user to the *Secondary Lines of Evidence: Modeling Results* screen.

10) ***Secondary Lines of Evidence:*** In each screen select the information that pertains to the site for both Modeling and Empirical results, click "Next" to continue to the next screen. Results for modeling studies are entered on the *Secondary Lines of Evidence: Modeling Results* screen. Next, results of any empirical evidence are entered on the *Secondary Lines of Evidence: Empirical Results* screen. To proceed click "Next". The Secondary Lines of Evidence portion of the software is complete.

11) ***Trend Analysis Menu:*** From the *Trend Analysis Menu*, select "MAROS Analysis" by clicking the button next to the label. This action will take the user to the *Lines of Evidence Summary by Well* screen.

12) ***MAROS Analysis:*** In each screen select to weight the Lines of Evidence or individual wells as pertains to your site, click "Next" to continue to the next screen. Results for all lines of evidence are summarized on the *Lines of Evidence Summary by Well* screen. Next, the choice to weight the Lines of Evidence by "All Chemicals" or "Individual Chemicals" is made on the *LOE Summary Weighting* screen. Continue to the *Results of LOE Weighting* screen to view the results in table form. Finally the option to weight individual wells is available on the *Lines of Evidence by Well Weighting* screen. The *Monitoring System Category* screen shows a summary of the source and tail well results for the COCs chosen, the Monitoring System Category is displayed for these results. To proceed click "Next". The Trend Analysis portion of the software is complete.

13) ***Main Menu:*** From the *Main Menu*, select "MAROS Output" by clicking the button next to the label. This action will take the user to the *MAROS Reports/Graphs* screen.

14) ***MAROS Reports/Graphs:*** Select the report or graph you would like to view, then click on the button next to the list. This action will take the user to the report or graph chosen. To print, select the print icon on the tool bar or select "Print" from the file menu. Click "Close" to exit the Report.

What COCs should I choose for my site?

The MAROS Tool can help the use to choose the Constituents of Concern for your site. Up to five COCs can be analyzed at one time by the MAROS software. To receive input from the software on how to choose COCs:

1) ***Follow directions for Importing/Entering Data above.***

2) ***Main Menu:*** From the *Main Menu*, select "Site Details" by clicking the button next to the label. This action will take the user to the *Site Information* screen.

3) ***Site Details:*** In each screen select the information that describes the site, click on "Next" to continue to the next screen. First, enter the site details on the *Site Information* screen. Next, define sample events on the *Sample Events* screen. Then select the representative wells in the Source and Tail zones on the *Source/Tail Zone Selection* screen. Continue to the *Constituents of Concern Decision* screen to choose the representative COCs for the site.

4) ***Constituents of Concern:*** From the *Constituents of Concern* screen, click on "Recommended COCs". The next screen, *Risk Level Assessment*, will show the data for COCs that are currently in the database to be evaluated. Choose from the list of generic Preliminary Remediation Goal (PRG) recommendations. Choose from the list of generic Preliminary Remediation Goal (PRG) recommendations. Click on the appropriate standard to be used in database comparisons for COC recommendations. Enter your own modifications to cleanup goals under "custom goals" in mg/L. The next screen, COC Decision screen shows up to 10 of the recommended COCs based on Toxicity, Prevalence, and Mobility. Enter up to 5 COCs for the site in the boxes to the left. If you would like a detailed view of the process used to make the COC recommendation, click on "Toxicity", "Prevalence" or "Mobility" at the left side of the screen. The information displayed in this screen can also be viewed in report

form, "COC Assessment Report" from the *MAROS Output* Screen. To proceed with the next step in the software click "Back".

How can I access the Sampling Optimization module?

The Sampling Optimization module is an optional extension of the MAROS software. It may optimize the sampling plan by eliminating redundant sampling locations and determining the lowest sampling frequencies for these sampling locations. To access the Sampling Optimization module, complete the following steps:

1) ***Start Screen:*** After starting the MAROS software, the *Start Screen* is shown, input user name and project name and click button *Start*. You will enter the *Main Menu*.

2) ***Main Menu:*** In the *Main Menu*, the *Sampling Optimization* module is the fourth option. The *Sampling Optimization* label is red and the button next to it is deactivated. Follow instructions and complete the three modules above the *Sampling Optimization* module in that order. They are *Data Management*, *Site Details* and *Trend Analysis*. After running through the three modules, go back to Main Menu, the button next to the label *Sampling Optimization* will be activated, click this button, the *Sampling Optimization* screen will appear.

3) ***Sampling Optimization:*** The sampling optimization screen is a main menu for two sub-modules: *Sampling Location Determination* and *Sampling Frequency Determination*. Now you can follow the instructions and perform the two analyses.

To View/Print Report:

4) ***Main Menu:*** After running through *Sampling Optimization* module, click button *Main Menu* to return to screen *Main Menu*. In screen *Main Menu*, click the button next to the label *MAROS Output*. The *MAROS Output Reports* screen will appear.

5) ***MAROS Output Reports:*** In this screen, from the *Report* listbox, select "*Sampling Location Optimization Report*" or "*Sampling Frequency Optimization Report*" by clicking on that item (available only after that module has been successfully performed). Then click button *View/Print Report* and follow instructions to view or print the report.

How will the Sampling Optimization module help me optimize a sampling plan?

The Sampling Optimization module is used to determine the minimal number of sampling locations and the lowest sampling frequencies that can still meet the requirements of spatial sampling and temporal sampling for the monitoring program. These analyses are based on each Constituent of Concern (COC) and so are the results. Lumped results considering all COCs are simply obtained by using the most stringent results among them. Both types of results are available in result reports.

1) ***Sampling Location Determination:*** This sub-module uses the Delaunay Method to eliminate "redundant" wells from the monitoring network based on spatial analysis. The analysis is performed based on a series of sampling events (a series of snapshots of the subsurface condition) for each COC. Major steps to be followed are :

a) ***Sampling Location: Delaunay Method****:* In this screen, select the series of sample events intended for analysis by defining the *From* and *To* sampling events and click *Confirm*. Then choose between *Access Module* and *Excel Module* (the latter one is available only when a single sampling event is chosen for analysis).

b) ***Sampling Location Determination - Access Module***: In this screen, set up the *Selected?* and *Removable?* properties of potential sampling locations and if needed change the optimization parameters by clicking button *Options*. Then click button *Preliminary Analysis* to proceed. All COCs will be analyzed and several steps are to be followed to complete this analysis.

Or

c) ***Sampling Location Determination - Excel Module****:* In this screen, set up the *Selected?* and *Removable?* properties of potential sampling locations for a COC and then click *Analysis*. The *xlsDelaunay* worksheet will pop up and the user is required to finish optimization there. After sending back the results for that COC from *xlsDelaunay* (by clicking *Back To Access* in *xlsDelaunay*), this screen will re-appear. Run through all COCs in the same way and click *Next* to proceed.

2) ***Sampling Frequency Determination:*** This sub-module uses the Modified CES method to determine the lowest sampling frequency for each sampling location. The method is based on the analysis of time-series data by assessing the Rate of Change (ROC) and Concentration Trend (CT) of each Constituent of Concern (COC) and considering both recent trends and overall (long-term) trends of the data. The analysis is performed according to each COC. Major steps to be followed are:

a) ***Sampling Frequency Determination****:* In this screen, define the "recent period" by selecting the *From* and *To* sampling events and then click button *Confirm*. Click button *Option* and change the *Rate of Change* parameters if necessary. Click *Analysis* to proceed.

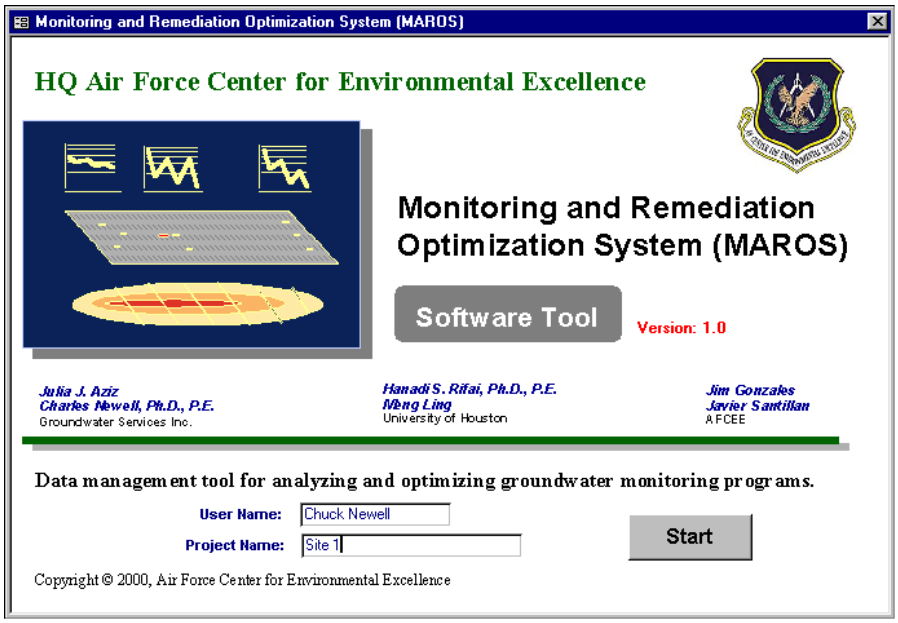
b) ***Sampling Frequency Recommendation***: View results for all COCs and click button *Next* to complete.

There is no order to follow in running the above two modules. The user can choose to run either module first and to view the result report once that module has been completely performed. The result report is organized in two parts: 1) the detailed results grouped by each COC and 2) the lumped all-in-one results after comparing all COCs by using the most stringent results among them. For detailed instructions on how to run these modules, refer to the next section MAROS DETAILED SCREEN DESCRIPTIONS.

MAROS DETAILED SCREEN DESCRIPTIONS

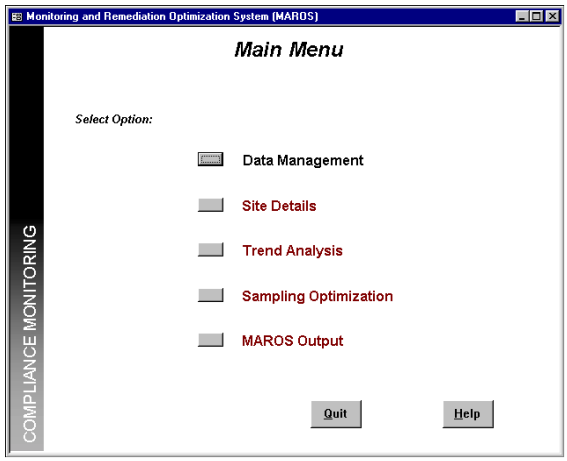
Start Screen

The Start Screen gives the user access to the software system. Enter the User name and Project Name in the boxes to the left of the Start Button. Then click "Start" to proceed to use the database software.



Utilizing the MAROS software is analogous to a train trip (Figure 1). You begin the expedition by importing your raw groundwater data that has been collected over several sampling periods from the field site of interest. As you journey through the software, you can get off at any station along the way. The results that you are presented with at each stop whether graphical or in a report will be based on increasingly more consolidated data. These data consolidation steps will lead to a higher degree of assumptions being used in order to reach a result or site specific recommendation. The assumptions you make along the way, will affect the outcome of the software tool results. Also, the validity of the results or recommendation will rely on the extent and quality of your data. For instance, more data doesn't necessarily mean better results. The data must meet minimum data requirements as to the frequency of sampling, duration of the sampling intervals for trend analysis and sampling density for the site as well as the quality of the measurements (decreased amount of false positives/negatives).

Main Menu



The Main screen serves at the center of the user interface. The user progressively steps through the Compliance Monitoring Trend Analysis and Optimization Evaluation process by navigating through the options displayed. As individual steps of the process are completed, options to select become successively available. The *Main Menu* screen allows the user to choose between performing:

- Data Management
- Site Details
- Trend Analysis
- Sampling Optimization
- MAROS Output

Select the desired option by clicking the applicable button.

Data Management

Allows data import of Excel and ERPIMS files, archiving current site data, and manual data addition.

Site Details

Initial definition of site specific data including choosing the "Source" and "Tail" wells, sample events and providing site-specific Constituents of Concern (COC's).

Trend Analysis

Allows the user to perform data reduction as well as trend analysis through both Primary Lines of Evidence and Secondary Lines of Evidence. Also allows the user to apply final Data Consolidation to the trend results.

Sampling Optimization

Allows the user to perform sampling optimization through various statistical methods used to determine the sampling location and sampling frequency.

MAROS Output

Allows the user to view/print site specific summary reports and graphs.

Quit

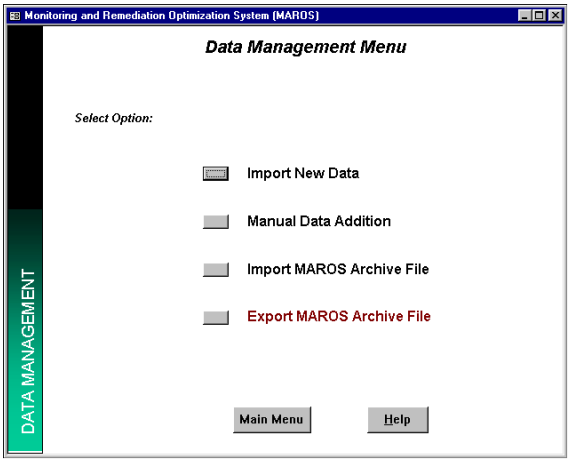
Closes the database program and Access. When the database is closed any data that you are currently working on will be erased. It is suggested that you Archive the current database if necessary before exiting.

Help

Provides additional information on software operation and screen-specific input requirements.

Data Management

The *Data Management* Menu (accessed from the *Main Menu*) is used to perform database operations such as importing, manual data addition and archiving. These operations are used initially to import site data into the software in order to perform analysis.



Choose the option of interest by clicking the applicable button.

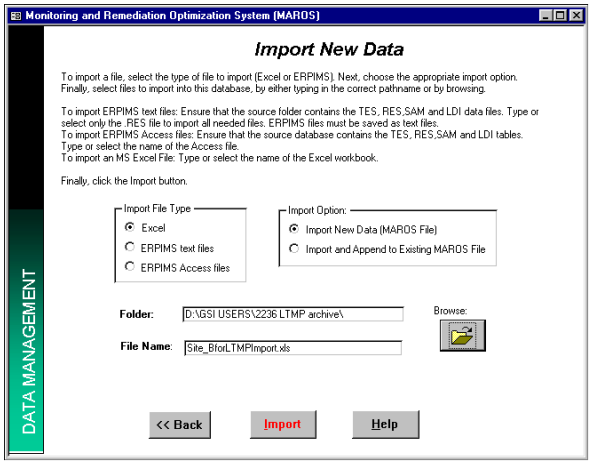
Main Menu: Returns the user to the *Main Menu*.

Help: Provides information on the screen-specific input requirements.

Import New Data

Import New Data (accessed from the *Data Management* screen) is used to choose between importing ERPIMS files or and Excel file in the standard LTMS format (see Appendix A.7) to the database as follows:

Choose the type of data import to be performed by clicking on the appropriate button.



To import data into the software:

1) Enter the full file path and filename of the file to import (or click the browse button to find the import file). The Folder and File name you choose will appear in the top two boxes. (See Notes below for ERPIMS and Excel file format/names.)

2) Choose the import option that corresponds to the import data. (Note that the "Import New Data" option will replace the existing data in the database.)

3) Click "Import" to proceed with importing the file to the existing database.

Back: Takes the user back to the *Data Management* screen.

Help: Provides information on the screen-specific input requirements.

NOTES:

To import an Excel 97 spreadsheet:

1) Type or select the name of the Excel workbook.
2) The import option requires an Excel file format with fields identical to those outlined in Appendix A.7**.** Each field must have the columns filled in. Do not import files with missing data, this will result in incorrect data evaluation within the software. The columns must include the field names in the first line. The template file "MAROS_ExcelTemplate.xls" is provided with the software with example data. Also, a list of permissible constituent names is found in the file, "MAROS_ConstituentList.xls".

To import ERPIMS files:

1) Ensure that the source folder contains the .SAM, .TES, .RES and .LDI data files.
2) Type or select only the .RES file to import all needed files**.

* * Before importing ERPIMS files they **must** be saved in text format in Microsoft Word 97 with fields identical to those already in the database system (i.e. the format matching that used by ERPIMS system). To save the ERPIMS files as text files, open each file (.SAM, .TES, .RES and .LDI files) one at a time in Word. You will be prompted to "Choose the encoding used for loading this file", check "Plain Text". When the file is opened in Word, under the Menu option click "Save as". You will be prompted to "Save as type:", choose "Text only (*.txt)". Make sure you do not have the .txt extension on the end of the file name, only the original file name with the .RES, .SAM, .TES or .LDI file extension should appear. All files should have the same name (e.g. Hillgwdata.RES, Hillgwdata.LDI, Hillgwdata.TES and Hillgwdata.TES). No field names should appear in the files.

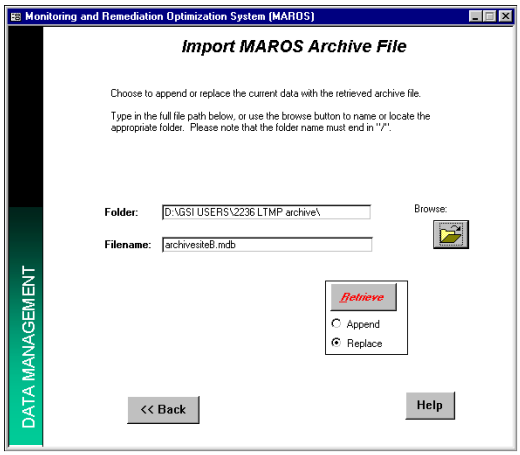
  There is a limit on the amount of data that can be opened in Microsoft Word 97, this will be controlled by the amount of RAM in your computer. The rule of thumb for large files is that your computer should have at least 3 times the amount of RAM as the size of the file. For instance if you have a 80 MB file you should have at least 256 MB of RAM to open this type of file in Word. If you do not know the amount of RAM on your computer, from the "Start" Button go to "Settings" and "Control Panel". In the control panel, open the "System" Icon and look at the "General" tab. This indicates the amount of RAM in your computer.

To import ERPIMS files from an Access database:

1) Type or select the name of the Access database.
2) Ensure that the tables included in the database file are named as follows SAM, .TES, .RES and .LDI data tables. The import option requires an Access file format with fields identical to those outlined in Appendix A.7**.** Each field must have the mandatory columns filled in. Do not import files with missing data, this will result in incorrect data evaluation within the software. The columns must include the field names as outlined in Appendix A.6. The template file "MAROS_AccessTemplate.mdb" is provided with the software with example data.

Import MAROS Archive File

Import Archive File (accessed from the *Data Management Menu* screen) is used to import previously archived data files as follows:



To import archived data into the full database:

1) Enter the full file path and filename of the archived file to import (or click the browse button to find the import file). The Folder and File name you choose will appear in the top two boxes.
2) Choose the import option that corresponds to the import data. (Note that the "Replace" option will replace the existing data in the database.)
3) Click "Retrieve" to proceed with importing the archived file to the existing database.

Back: Takes the user back to the *Data Management* screen.

Help: Provides information on the screen-specific input requirements.

Export MAROS Archive File

Import Archive File (accessed from the *Data Management Menu* screen) is used to import previously archived data files.

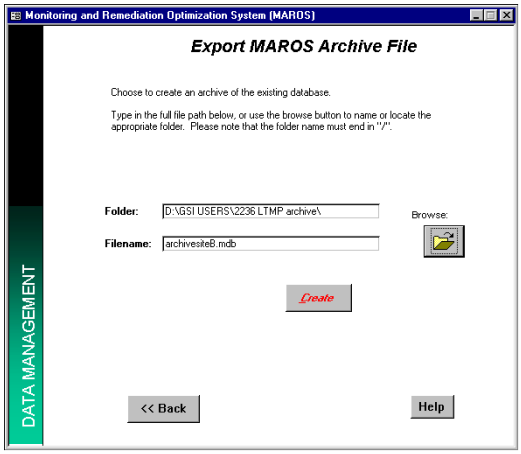
To export data into an archive database:

1) Enter the full file path and filename of the archived file to export (or click the browse button to find the archive file to overwrite). The Folder and File name you choose will appear in the top two boxes.

2) Click "Create" to proceed with exporting the data to the archive file.

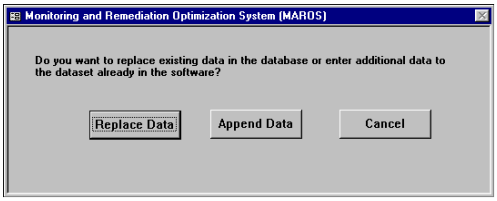
Back: Takes the user back to the *Data Management* screen.

Help: Provides information on the screen-specific input requirements.



Manual Data Addition

Manual Record Addition (accessed from the *Data Management Menu* Screen) can be used to add individual Records to the database.



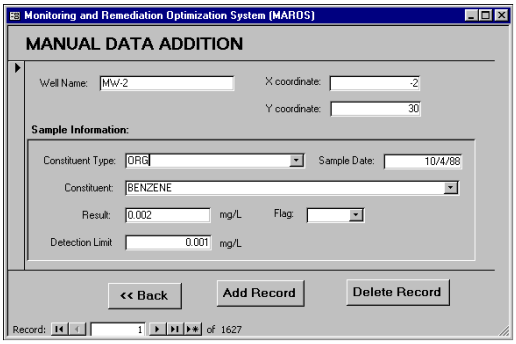
Steps for use:

1) Choose to "Replace Data" or "Append Data" to the groundwater data already in the software.

2) Fill in the appropriate information within each field. Fields such as "Constituent Type" and Constituent have dropdown boxes to assist in data entry. Choose Constituent Type before choosing the Constituent.

Note: If the result is "ND" then fill in the Detection Limit.

3) Review information before adding the record. When all the data is entered, click on the "Add Record" button.



Add Record: To add a new record, choose the entries from the selection boxes or type in the record information.

Delete Record: To delete the record currently shown on the screen. Deleting a record is a permanent operation.

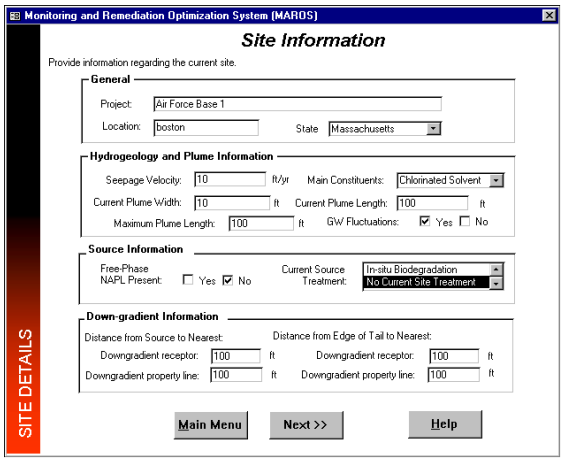
Alls fields should be filled in to ensure minimum information for added records. However, if X and Y coordinates are unknown these fields can be left blank.

Back: Takes the user back to the *Data Management* screen.

Help: Provides information on the screen-specific input requirements.

Site Details

Site Information (accessed from the *Main Menu* Screen) is the first step in defining the site type as well as parameters unique to the site.



Fill in the appropriate information within each field. Fields such as "State" and "Current Source Treatment" have dropdown boxes to assist in data entry.

Note: All fields on this form are mandatory entry. The user will be prompted if the fields are not filled in.

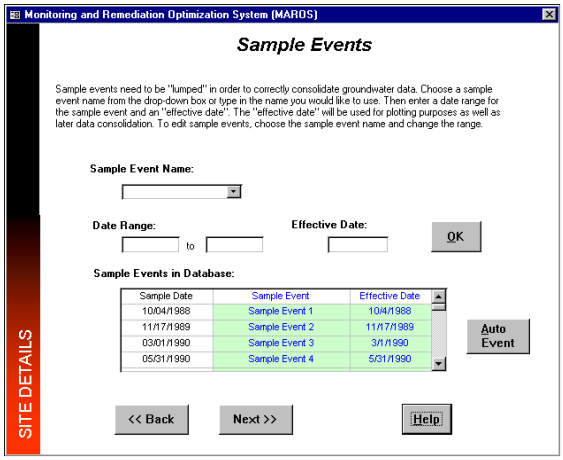
Next: Takes the user to the *Sample Events* screen.

Main Menu: Takes the user back to the *Main Menu* screen.

Help: Provides information on the screen-specific input requirements.

Site Details

Sample Events (accessed from the *Site Information* screen) allows the user to define sample events and dates to be used for graphing and data consolidation.



Steps for use:

1) Choose a sample event name from the drop-down box or type in the name you would like to use.
2) Enter a date range for the sample event (e.g. 10/04/1998 to 10/06/1998) and an "effective date" (e.g. 10/04/1998). The "effective date" will be used for plotting purposes and further data consolidation.
3) Select "OK" to update the sample event information.

Note: To edit sample events, choose the sample event name and change the range.

Auto Event: Allows the user to update sample events automatically. The software will assign the actual sample date as the effective date. Also, each sample event will be assigned to a unique original date. This option should only be used if the data only has one date per sampling event.

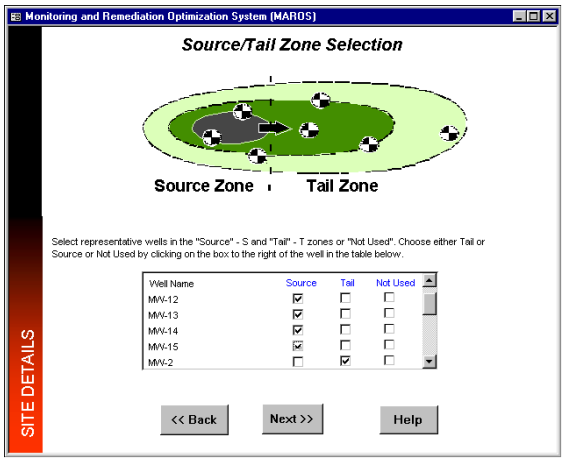
Next: Takes the user to the *Source/Tail Zone Selection* screen.

Back: Returns the user back to the *Site Information* screen.

Help: Provides information on the screen-specific input requirements.

Site Details

Source/Tail Zone Selection (accessed from the *Sample Events* Screen) allows the user to define the well type for the wells in the database. The MAROS software divides the wells for the site into two different zones (e.g. "Source" zone and "Tail" zone). The "Source" area include zones with NAPLs, contaminated vadose zone soils, and areas where aqueous-phase releases have been introduced into groundwater. The source area is generally the location with the highest groundwater concentrations of constituents of concern. The downgradient groundwater plume ("Tail") zone is the area downgradient of the contaminant source zone. The Tail only contains contaminants in the dissolved phase and the sorbed phase, but contains no sources of contamination.



Select representative wells in the "Source" - S and "Tail" - T zones or "Not Used". Choose either Tail or Source or Not Used by clicking on the box to the right of the well in the table. Select representative wells in the "Source" and "Tail" zones.

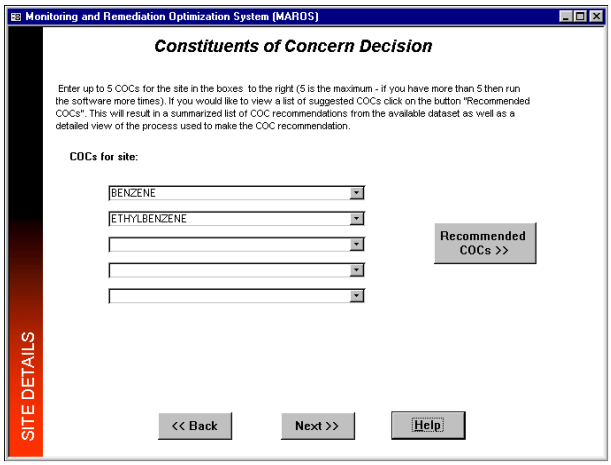
Next: Takes the user to the *COC Decision* screen.

Back: Returns the user back to the *Sample Events* screen.

Help: Provides information on the screen specific input requirements.

Site Details

Constituents of Concern Decision (accessed from the *Source/Tail Zone Selection* Screen) allows the user to define up to five constituents to be evaluated at the site.



Enter up to 5 COCs for the site in the boxes to the right (5 is the maximum - if you have more than 5 then run the software more times). If you would like to view a list of suggested COCs click on the button "Recommended COCs". This will result in a summarized list of COC recommendations from the available dataset as well as a detailed view of the process used to make the COC recommendation.

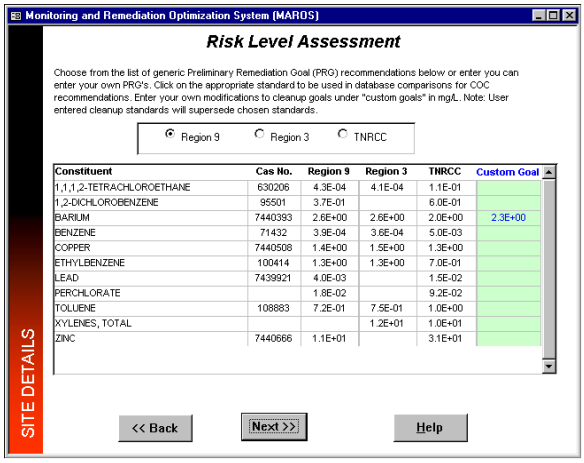
Next: Takes the user to the *Initial Data Table* screen.

Back: Returns the user back to the *Source/Tail Zone Selection* screen.

Help: Provides information on the screen-specific input requirements.

Site Details

Risk Level Assessment (accessed from the *COC Decision* screen) allows the user to choose a preliminary remediation goal (PRG) used to screen representative concentrations from the dataset.



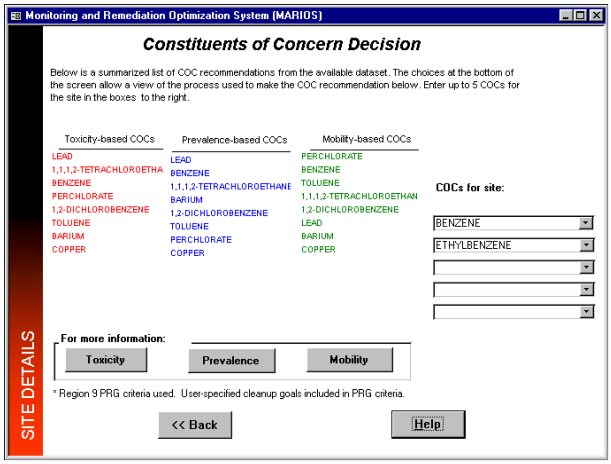
Choose from the list of generic Preliminary Remediation Goal (PRG) recommendations. Click on the appropriate standard to be used in database comparisons for COC recommendations. Enter your own modifications to cleanup goals under "custom goals" in mg/L. Note: User entered cleanup standards will supersede chosen standards.

Back: Returns the user to the *COC Decision* screen.

Next: Takes the user to the *COC Recommendation* Screen.

Help: Provides information on the screen-specific input requirements.

COC Recommendation (accessed from the *Risk Level Assessment* screen) allows the user to choose COCs based on Toxicity, Prevalence and Mobility of samples from the dataset.

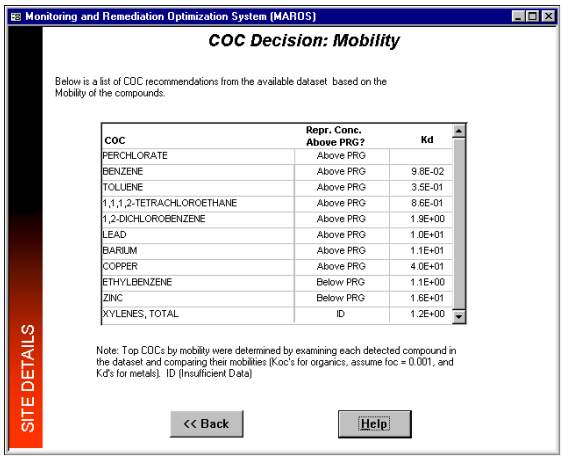


Enter up to 5 COCs for the site in the boxes to the left. If you would like a detailed view of the process used to make the COC recommendation, click on "Toxicity", "Prevalence" or "Mobility at the left side of the screen.

The information displayed in this screen can also be viewed in report form, "COC Assessment Report" from the *MAROS Output* Screen (see Appendix A.8 for an example report).

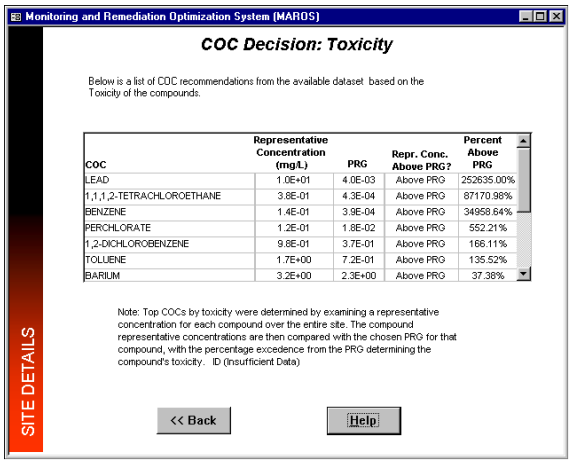
Back: Returns the user to the *Risk Level Assessment* screen.

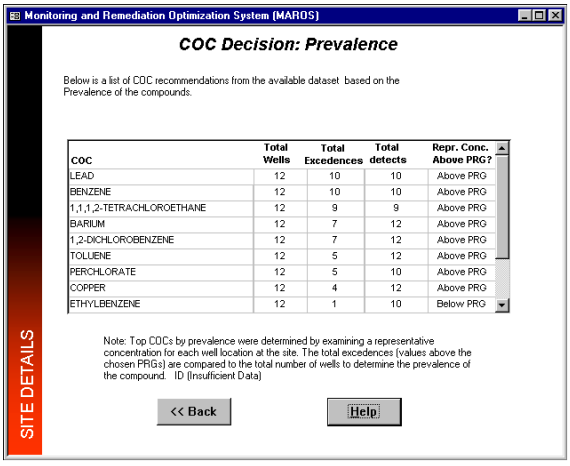
Help: Provides information on the screen-specific input requirements.



COC Decision Mobility shows a list of COC recommendations from the available dataset based on the Mobility of the compounds. Top COCs by mobility were determined by examining each detected compound in the dataset and comparing their mobilities. (Koc's for organics, assume foc = 0.001, and Kd's for metals). Compounds listed first are those above the PRG and are shown on the *COC Decision* screen.

COC Decision Toxicity shows a list of COC recommendations from the available dataset based on the Toxicity of the compounds. Top COCs by toxicity were determined by examining a representative concentration for each compound over the entire site. The compound representative concentrations are then compared with the chosen PRG for that compound, with the percentage excedence from the PRG determining the compound's toxicity. Compounds listed first are those above the PRG and are shown on the *COC Decision* screen.





COC Decision Prevalence shows a list of COC recommendations from the available dataset based on the Prevalence of the compounds. Top COCs by prevalence were determined by examining a representative concentration for each well location at the site. The total excedences (values above the chosen PRGs) are compared to the total number of wells to determine the prevalence of the compound. Compounds listed first are those above the PRG and are shown on the *COC Decision* screen.

Back: Returns the user to the *COC Decision* screen.

Help: Provides information on the screen-specific input requirements

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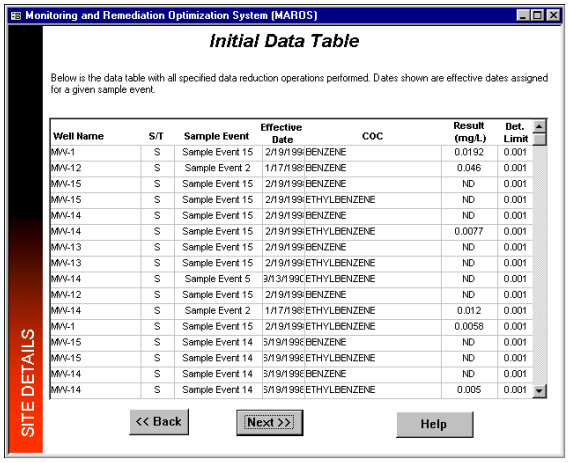
Site Details

Initial Data Table (accessed from the *COC Decision* screen) allows the user to view the initial data table with the COCs chosen as well as the sample events defined and effective dates. This table is not available for editing.

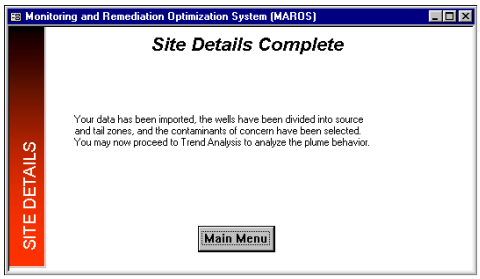


Back: Returns the user to the *COC Decision* screen.

Next: Takes the user to the *Main Menu* screen.

Help: Provides information on the screen-specific input requirements.

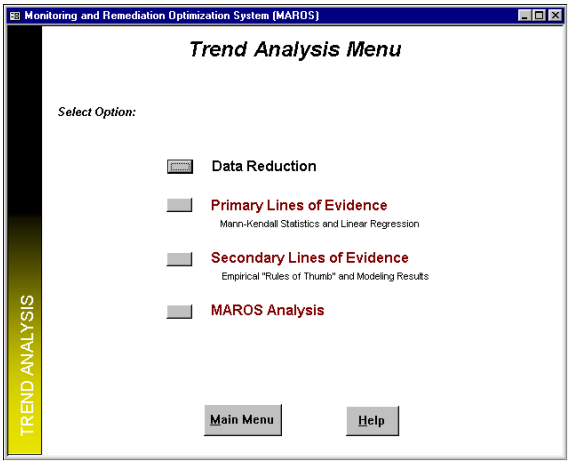
At this point your data has been imported, the wells have been divided into source and tail zones, and the constituents of concern have been selected. You may now proceed to Trend Analysis to analyze the plume behavior.



Main Menu: Returns the user to the *Main Menu*.

Trend Analysis

The *Trend Analysis Menu* screen serves at the center of the trend analysis user interface. The user progressively steps through the Long Term Monitoring Trend Analysis process by navigating through the options displayed. As individual steps of the process are completed, options to select become successively available. The *Trend Analysis Menu* screen allows the user to choose between performing:



- Data Reduction
- Primary Lines of Evidence
- Secondary Lines of Evidence
- MAROS Analysis

Select the desired option by clicking the applicable button.

The functions accessed by each choice are as follows:

Data Reduction

Allows consolidation of data based on dates as well as consolidating duplicates.

Primary Lines of Evidence

Perform Mann-Kendall Analysis and Linear Regression Analysis.

Secondary Lines of Evidence

Enter applicable modeling data and/or empirical data.

MAROS Analysis

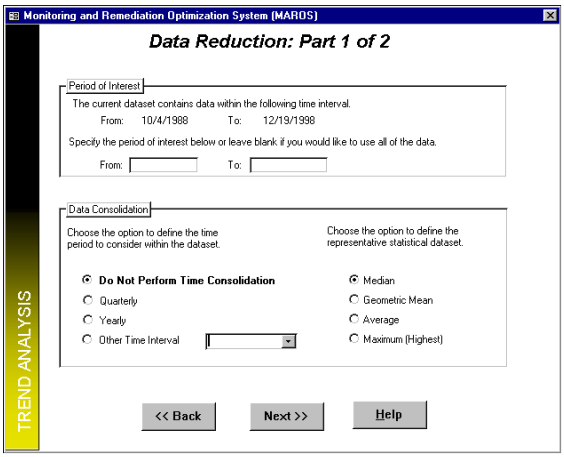
Allows user to weight the trend analysis data and weight well data. Final suggested monitoring system categories for each COC are displayed.

Help

Provides additional information on software operation and screen-specific input requirements.

Data Reduction

Data Reduction: *Part 1 of 2* (accessed from the *Trend Analysis Menu* screen) allows the user to consolidate the data based on time intervals and parameters chosen.



Steps for use:

1) The box at the top of the screen indicates the current dataset time range. The user should specify the period of interest in the boxes below or leave blank if you would like to use all of the data.
2) Choose the option to define the time period to consider within the dataset by clicking on the options on the bottom left of the screen. If you do not wish to perform any data consolidation, choose "Do Not Perform Time Consolidation".
3) Choose the option to define the representative statistical dataset within the consolidated time interval in the bottom right of the screen. Note: This option is not needed if you have chosen "Do Not Perform Time Consolidation".

Back: Returns the user to the *Trend Analysis Menu* screen.

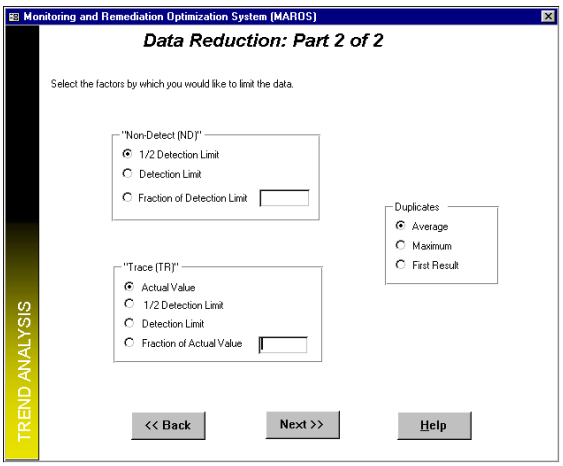
Next: Takes the user to the *Data Reduction Part 2 of 2* Screen.

Help: Provides information on the screen-specific input requirements.

Data Reduction

Data Reduction: *Part 2 of 2* (accessed from the *Data Reduction Part 1 of 2* screen) allows the user to consolidate the data based on concentration parameters chosen.

Select the factors by which you would like to limit the data.



"Duplicates": Choose the option to consolidate duplicates. Note: Duplicates are samples that have the same constituent, date, and well name. If you have given the same "effective date" to two samples they will be consolidated as duplicates.

"Non-Detect (ND)": Choose the number value you would like to represent a non-detect result in the data.

"Trace (TR)": Choose the number value you would like to represent a Trace result in the data. (The "TR" flag is equivalent to the "J" flag used by most labs, to indicate a result that is reported but is below the method detection limit)

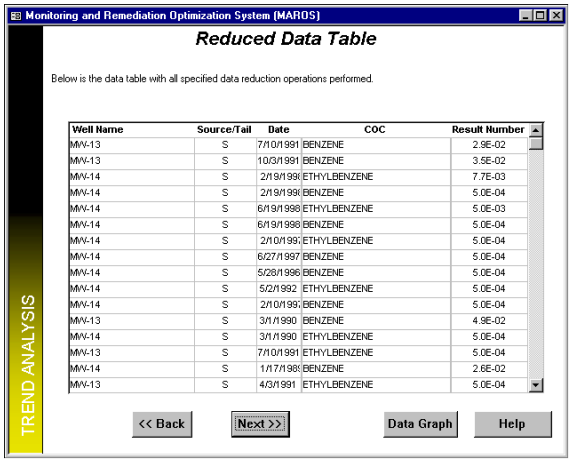
Back: Returns the user to the *Data Reduction Part 2 of 2* screen.

Next: Takes the user to the *Reduced Data Table* Screen.

Help: Provides information on the screen-specific input requirements.

Data Reduction

Reduced Data Table (accessed from the *Data Reduction Part 2 of 2* screen) allows the user to view the reduced data table with the COCs chosen as well as the data consolidation performed. This table is not available for editing.



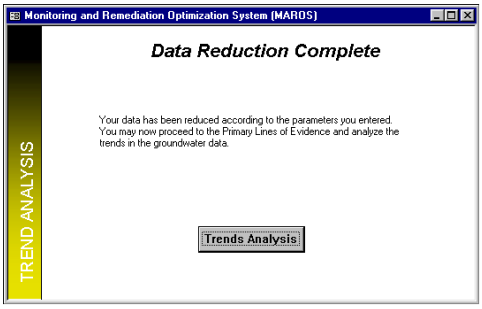
Back: Returns the user to the *Data Reduction Part 2 of 2* screen.

Next: Takes the user to the *Main Menu* screen.

Help: Provides information on the screen-specific input requirements.

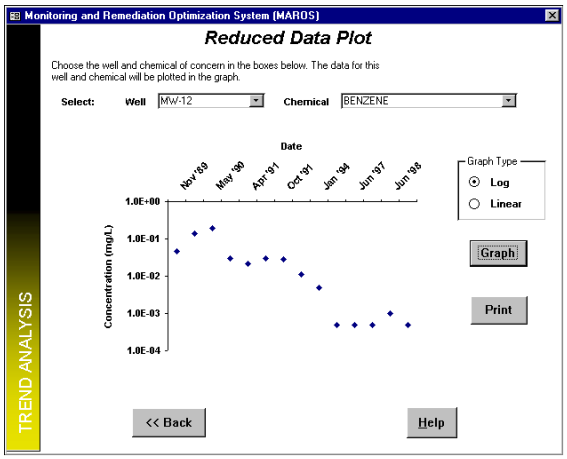
Data Graph: Provides a tool for viewing the reduced data in log or linear graph form.

At this point your data has been reduced according to the parameters you entered. You may now proceed to the Primary Lines of Evidence and analyze the trends in the groundwater data.



Data Reduction

Reduced Data Plot (accessed from the *Reduced Data Table* screen) allows the user to view the reduced data in graphical form.



Choose the Well and Chemical of interest from the dropdown boxes at the top of the screen. Choose the graph type (i.e. Log or Linear). Click "Graph" on graph to proceed.

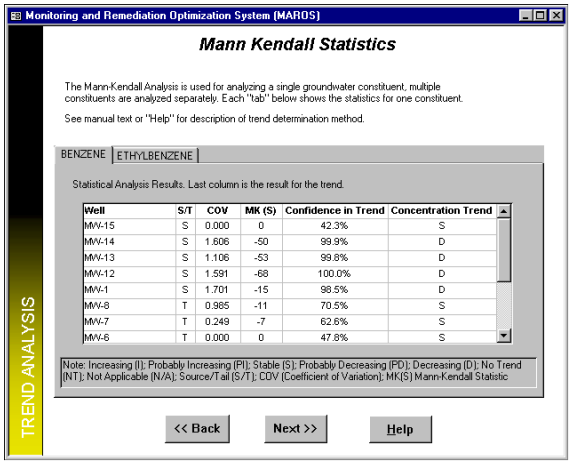
To print the current graph, click "Print" to proceed.

Back: Returns the user to the *Reduced Data Table* screen.

Help: Provides information on the screen-specific input requirements.

Primary Lines of Evidence

Mann-Kendall Statistics (accessed from the *Trend Analysis Menu*) allows the user to view the Mann-Kendall Trend Analysis results by well and constituent.



To navigate the results for individual constituents click on the tabs at the top of the screen.

COV: The Coefficient of Variation (COV) is a statistical measure of how the individual data points vary about the mean value. The coefficient of variation, defined as the standard deviation divided by the average. Values near 1.00 indicate that the data form a relatively close group about the mean value. Values either larger or smaller than 1.00 indicate that the data show a greater degree of scatter about the mean.

MK (S): The Mann-Kendall Statistic (S) measures the trend in the data. Positive values indicate an increase in constituent concentrations over time, whereas negative values indicate a decrease in constituent concentrations over time. The strength of the trend is proportional to the magnitude of the Mann-Kendall Statistic (i.e., large magnitudes indicate a strong trend).

Confidence in Trend: The "Confidence in Trend" is the statistical confidence that the constituent concentration is increasing (S>0) or decreasing (S<0).

Concentration Trend: The "Concentration Trend" for each well is determined according to the rules outlined in Appendix A. Results for the trend include: Increasing, Probably Increasing, No Trend, Stable, Probably Decreasing, Decreasing or Not Applicable (Insufficient Data).

The information displayed in this screen can also be viewed in report form, "Mann-Kendall Statistics Report" from the *MAROS Output* Screen (see Appendix A.8 for an example report). For further details on the Mann-Kendall Analysis Method see Appendix A.1.

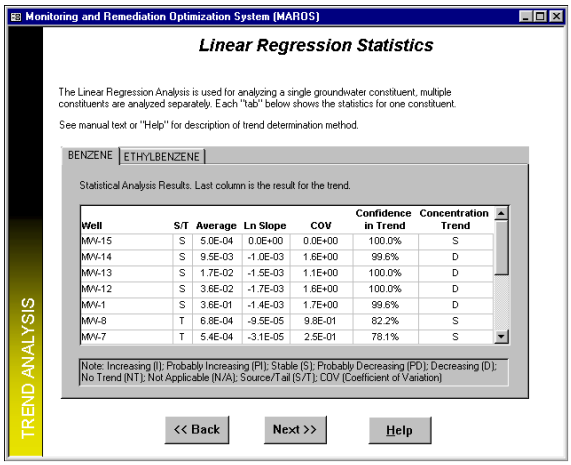
Back: Returns the user to the *Trend Analysis Menu*.

Next: Takes the user to the *Linear Regression* Screen.

Help: Provides information on the screen-specific input requirements.

Primary Lines of Evidence

Linear Regression Statistics (accessed from the *Mann-Kendall Statistics* screen) allows the user to view the Linear Regression Analysis results by well and constituent.



To navigate the results for individual constituents click on the tabs at the top of the screen.

COV: The Coefficient of Variation (COV) is a statistical measure of how the individual data points vary about the mean value. The coefficient of variation, defined as the standard deviation divided by the average. Values near 1.00 indicate that the data form a relatively close group about the mean value. Values either larger or smaller than 1.00 indicate that the data show a greater degree of scatter about the mean.

Slope: The slope of the least square fit through the given data indicates the trend in the data. Positive values indicate an increase in constituent concentrations over time, whereas negative values indicate a decrease in constituent concentrations over time.

Confidence in Trend: The "Confidence in Trend" is the statistical confidence that the constituent concentration is increasing (slope>0) or decreasing (slope<0).

Concentration Trend: The "Concentration Trend" for each well is determined according to the rules outlined in Appendix A. Results for the trend include: Increasing, Probably Increasing, No Trend, Stable, Probably Decreasing, Decreasing or Not Applicable (Insufficient Data).

The information displayed in this screen can also be viewed in report form, "Linear Regression Statistics Report" from the *MAROS Output* Screen (see Appendix A.8 for an example report). For further details on the Linear Regression Analysis Method see Appendix A.1.

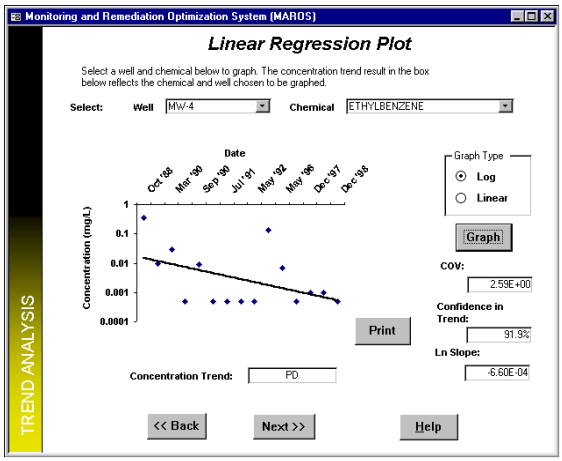
Back: Returns the user to the *Mann Kendall Statistics* Screen.

Next: Takes the user to the *Linear Regression* Screen.

Help: Provides information on the screen-specific input requirements.

Primary Lines of Evidence

Linear Regression Plot (accessed from the *Linear Regression* screen) allows the user to view the linear regression data in graphical form.



Choose the Well and chemical of interest from the dropdown boxes at the top of the screen. Choose the graph type (i.e. Log or Linear). Click "Graph" on graph to proceed.

To print the current graph, click "Print" to proceed.

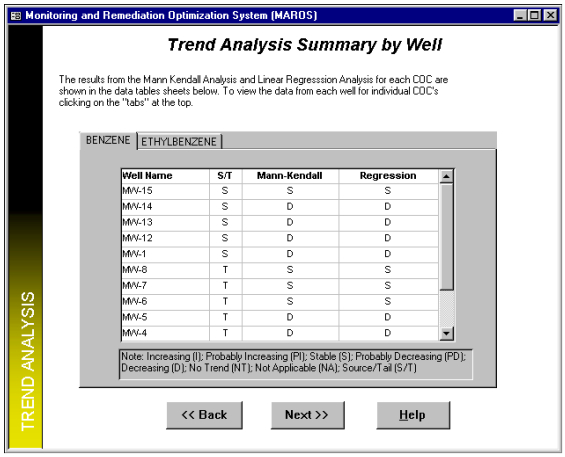
Back: Returns the user to the *Linear Regression* screen.

Next: Returns the user to the *Primary Lines Summary* screen.

Help: Provides information on the screen-specific input requirements.

Summarizing Primary Lines of Evidence

Trend Analysis Statistics Summary by Well (accessed from the *Linear Regression Plot* screen) allows the user to view the Mann-Kendall Trend Analysis and Linear Regression Analysis results by well and constituent.



To navigate the results for individual constituents click on the tabs at the top of the screen.

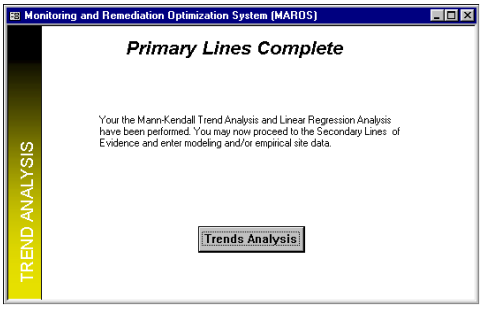
The information displayed in this screen can also be viewed in report form, "Lines of Evidence Summary Report" from the *MAROS Output* Screen.

Back: Returns the user to the *Linear Regression Plot*.

Next: Takes the user to the *Main Menu* Screen.

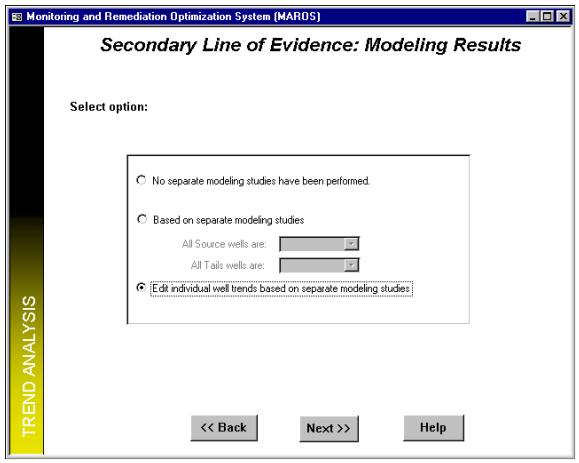
Help: Provides information on the screen-specific input requirements.

At this point the Mann-Kendall Trend Analysis and Linear Regression Analysis have been performed. You may now proceed to the Secondary Lines of Evidence and enter modeling and/or empirical site data.



Secondary Lines of Evidence

Secondary Line of Evidence: Modeling Results (accessed from the *Trend Analysis Menu* screen) allows the user to enter modeling results by well and constituent or for all source or all tail wells.



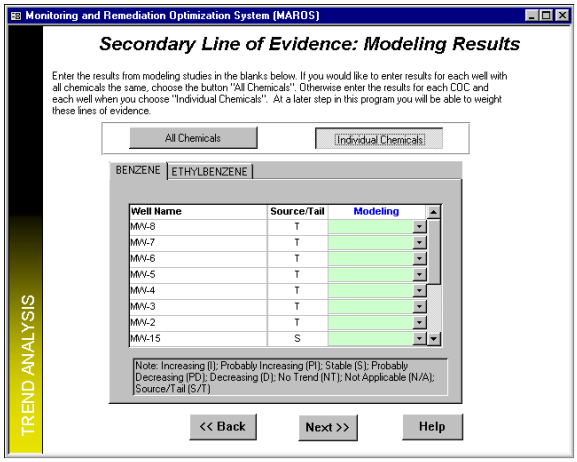
Options include entering modeling trend results i) based on separate modeling studies for both source and tail wells; ii) individual well trends based on separate modeling studies. If there are no modeling results choose the option "No separate modeling studies have been performed".

Back: Returns the user to the *Trend Analysis Menu*.

Next: Takes the user to the *Secondary Line of Evidence* screen. Note: If "Edit individual well trends based on separate modeling studies" is chosen, the next screen will allow this data entry.

Help: Provides information on the screen-specific input requirements.

Secondary Line of Evidence: Modeling Results allows the user to enter modeling results by well and constituent.

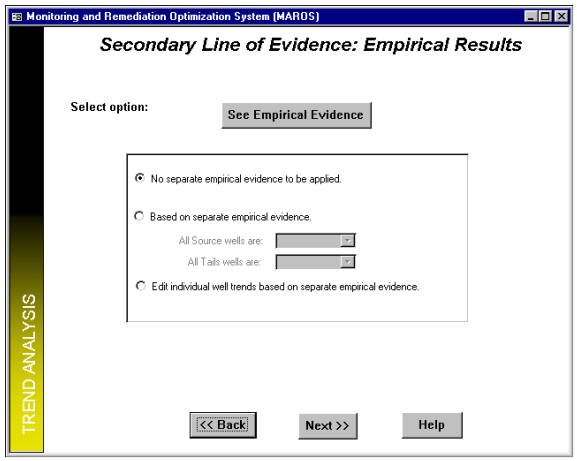


Enter the results from modeling studies (e.g. Increasing (I), Stable (S), etc.) in the blanks provided next to the well name. To navigate the results for individual constituents click on the tabs at the top of the screen. If you would like to weight all chemicals the same choose the button "All Chemicals". Otherwise enter the results for each COC and each well when you choose "Individual Chemicals". At a later step in this program you will be able to weight these lines of evidence.

Modeling results should be taken from fate and transport models that take site specific data and predict the ultimate extent of constituent migration (either for natural attenuation process or site undergoing remediation). Results for the modeling trend that can be entered in the software include: Increasing (I), Probably Increasing (PI), No Trend (NT), Stable (S), Probably Decreasing (PD), Decreasing (D) or Not Applicable (NA-Insufficient Data).

Secondary Lines of Evidence

Secondary Line of Evidence: Empirical Results (accessed from the *Secondary Line of Evidence: Modeling Results* screen) allows the user to enter empirical trend information by well and constituent or for all source or all tail wells. The rationale and limitations to this approach is outlined in Appendix A.4.



Options include entering empirical trend results i) based on separate empirical evidence for both source and tail wells; ii) individual well trends based on separate empirical rules. If there are no empirical results choose the option "No separate empirical evidence to be applied".

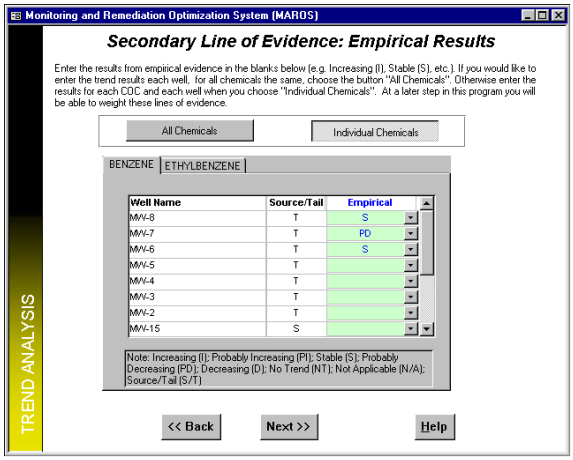
See Empirical Evidence: Takes the user to the *Empirical Evidence,* by State.

Back: Returns the user to the *Modeling Results*.

Next: Takes the user to the *Secondary Line of Evidence Summary* Screen. Note: If "Edit individual well trends based on separate empirical studies" is chosen, the next screen will allow this data entry.

Help: Provides information on the screen-specific input requirements.

Secondary Line of Evidence: Empirical Results allows the user to enter empirical results by well and constituent.

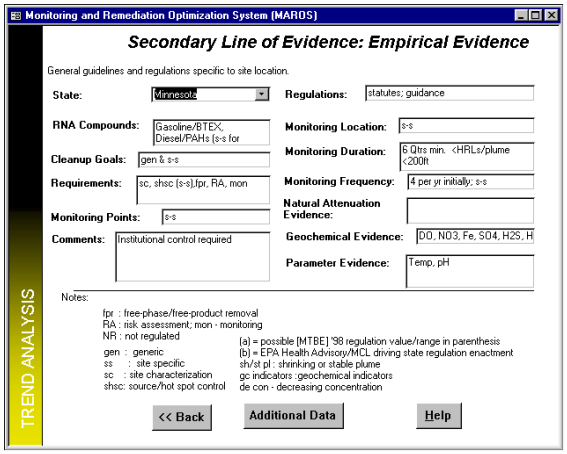


Enter the results from empirical evidence (e.g. Increasing (I), Stable (S), etc.) in the blanks provided next to the well name. To navigate the results for individual constituents click on the tabs at the top of the screen. If you would like to weight all chemicals the same choose the button "All Chemicals". Otherwise enter the results for each COC and each well when you choose "Individual Chemicals". At a later step in this program you will be able to weight these lines of evidence.

Empirical results should be developed on the basis of data from previous similar site studies (e.g. "plume-a-thon" studies such as the Lawrence Livermore study, the BEG studies and the AFCEE chlorinated database). For further Empirical result guidelines see Appendix A.4. Also, state rules are provided to guide the user to site-specific guidelines for natural attenuation. Results for the empirical trend that can be entered in the software include: Increasing (I), Probably Increasing (PI), No Trend (NT), Stable (S), Probably Decreasing (PD), Decreasing (D) or Not Applicable (NA- Insufficient Data).

Secondary Line of Evidence: Empirical Evidence (accessed from the *Secondary Line of Evidence: Empirical Results* screen) gives the user guidance for empirical evidence for trends by State.

To view information pertaining to the state of interest, choose the state name from the drop down box at the top left. Information on general guidelines and regulations specific for Long Term Monitoring are shown.



Additional Data: Takes the user to the *Screen Criteria,* by State.

Back: Returns the user to the *Empirical Results*.

Help: Provides information on the screen-specific input requirements.

Sources for this information include:

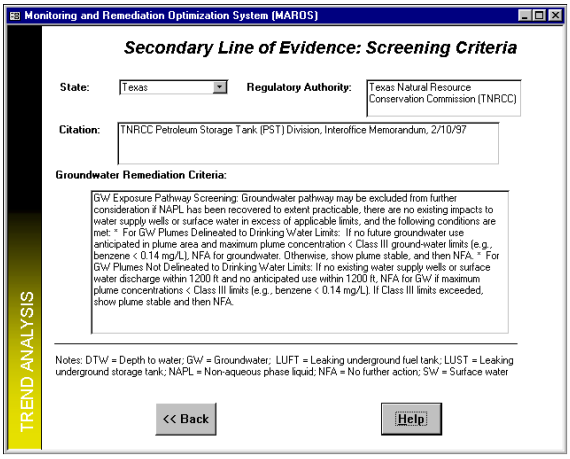
Martinson, M., 1998 and Groundwater Services, Inc. (www.gsi-net.com/ rbcapol)

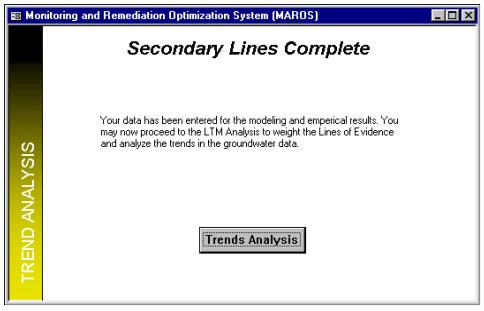
Secondary Line of Evidence: Screening Criteria (accessed from the *Secondary Line of Evidence: Empirical Evidence* screen) gives the user additional guidance for empirical evidence for trends by State.

To view information pertaining to the state of interest, choose the state name from the drop down box at the top left. Information on general guidelines and regulations specific for Long Term Monitoring are shown.

Back: Returns the user to the *Empirical Evidence*.

Help: Provides information on the screen-specific input requirements.

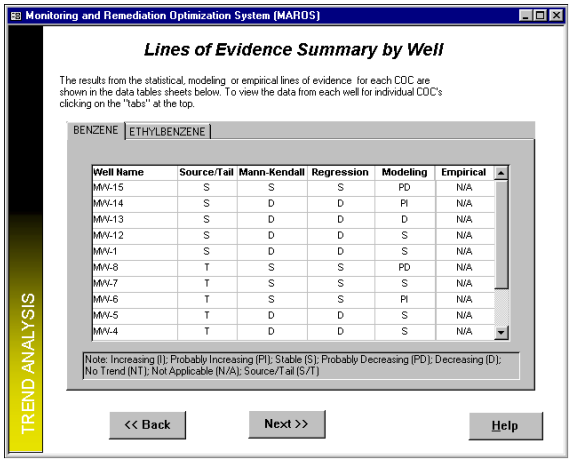




At this point the Modeling and Empirical Trend results have been entered. You may now proceed to the LTM (Long Term Monitoring) Analysis to weight the Lines of Evidence (LOE) and analyze the trends in the groundwater data.

MAROS Analysis

Lines of Evidence Summary by Well (accessed from the *Trend Analysis Menu* screen) allows the user to view the Mann-Kendall Trend Analysis, Linear Regression Analysis, Modeling and Empirical results by well and constituent.



To navigate the individual constituent results, click on the tabs at the top of the screen.

The information displayed in this screen can also be viewed in report form, "Lines of Evidence Summary Report" from the *MAROS Output* Screen (see Appendix A.8 for an example report).

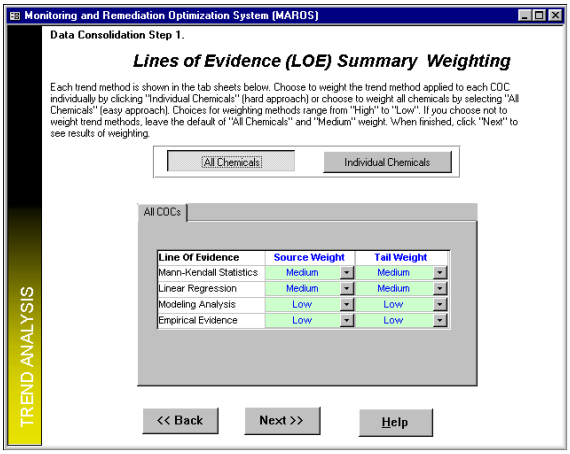
Back: Returns the user to the *Trend Analysis Menu*.

Next: Takes the user to the *Lines of Evidence Summary Weighting* Screen.

Help: Provides information on the screen-specific input requirements.

MAROS Analysis – LOE Weighting

Lines of Evidence Summary by Weighting (accessed from the *LOE Summary by Well* screen) allows the user to weight the individual lines of evidence (i.e. Mann-Kendall Trend Analysis, Linear Regression Analysis, Modeling and Empirical results).



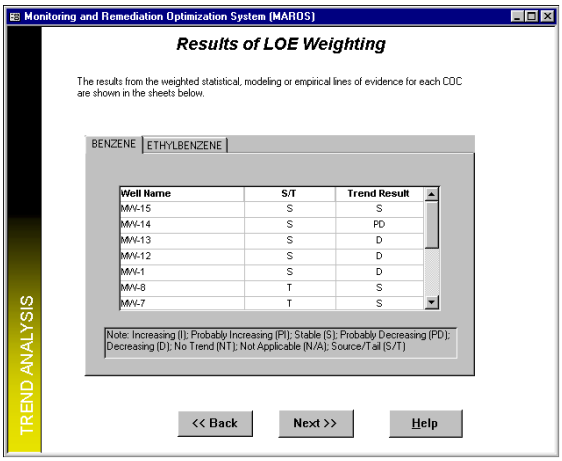
Each trend method is shown in the tab sheets. Choose to weight the trend methods applied to each COC individually by clicking "Individual Chemicals" (difficult approach) or choose to weight all chemicals by selecting "All Chemicals" (easy approach). Choices for weighting methods range from "High" to "Low". If you choose not to weight trend methods, leave the default of "All Chemicals" and "Medium" weight. If you choose to not include the "Empirical Evidence", choose "Not Used". When finished, click "Next" to see results of weighting.

Back: Returns the user to the *Lines of Evidence Summary by Well* screen.

Next: Takes the user to the *Results of LOE Weighting* Screen.

Help: Provides information on the screen-specific input requirements.

Results of LOE Weighting (accessed from the *Lines of Evidence Summary by Weighting* screen) allows the user to view the weighted statistical, modeling and empirical lines of evidence for each COC.



To navigate the results for individual constituents, click on the tabs at the top of the screen.

Back: Returns the user to the *Lines of Evidence Summary by Weighting*.

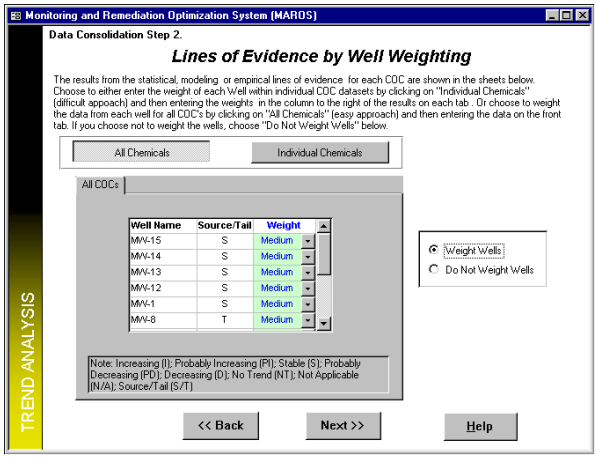
Next: Takes the user to the *Lines of Evidence by Well Weighting* Screen.

Help: Provides information on the screen-specific input requirements.

MAROS Analysis – Weighting Wells

Lines of Evidence by Well Weighting (accessed from the *Results of LOE Weighting* screen) allows the user to weight the individual wells by all chemicals or by constituent.

To weight wells, select "Weight Wells" on the right side of the screen. Then, choose to either enter the weight of each well within individual COC datasets by clicking on "Individual Chemicals" (difficult approach) and then entering the weights in the column to the right of the results on each tab . Or choose to weight the data from each well for all COC's by clicking on "All Chemicals" (easy approach) and then entering the data on the front tab.



Choices for weighting methods range from "High" to "Low". If you choose to weight trend methods, select "Do Not Weight Wells" on the right side of the screen. When finished, click "Next" to see results of weighting.

Back: Returns the user to the *Lines of Evidence Summary by Well*.

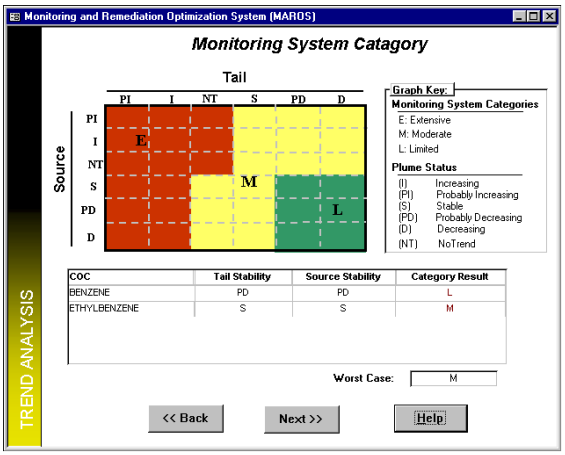
Next: Takes the user to the *Results of LOE Weighting* Screen.

Help: Provides information on the screen-specific input requirements.

MAROS Analysis- Overall Analysis

Monitoring System Category (accessed from the *Lines of Evidence by Well Weighting* screen) allows the user to view the suggested design category for each COC.

Trend results for both tail and source wells are given. From these results a monitoring system category that characterizes the site for an individual constituent is shown. Categories include Extensive (E), Moderate (M), and Limited (L) long term monitoring required for the site.

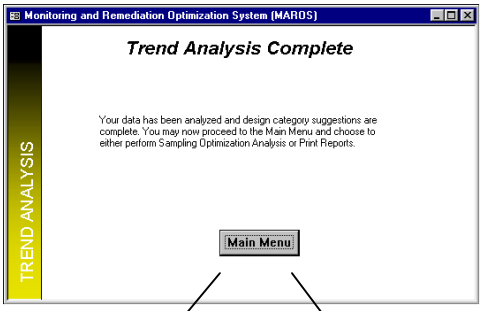


Back: Returns the user to the *Lines of Evidence by Well Weighting*.

Next: Takes the user to the *Main Menu* Screen.

Help: Provides information on the screen-specific input requirements.

At this point in the software, your data has been analyzed and design category suggestions are complete. You may now proceed to the Main Menu and choose to either perform Sampling Optimization Analysis or choose MAROS Output (Print Standard Reports/Graphs).



Standard Approach

MOST USERS HERE

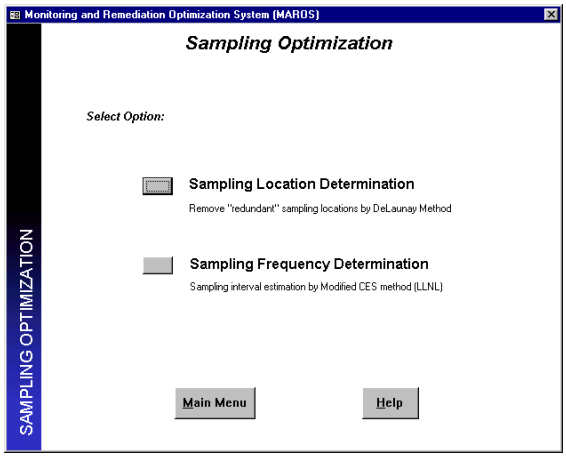
MAROS Output: (Choose to Print/View Reports). Standard Reports, including the one-page heuristic approach to sampling optimization based on plume stability and site parameters with results for sampling frequency, duration and density. **GOTO PAGE 57**

Detailed Approach

Sampling Optimization: Rigorous detailed statistical approach to sampling optimization with modules to optimize sampling location by Delaunay Triagulation and Sampling Frequency by the Modified CES method. **GOTO PAGE 41**

Sampling Optimization: Detailed Approach

The *Sampling Optimization* screen (accessed from screen *Main Menu* by clicking *Sampling Optimization*) is the main menu for sampling optimization analyses. It allows the user to choose between performing:



- Sampling Location Determination
- Sampling Frequency Determination

The functions accessed by each choice are as follows:

Sampling Location Determination

Optimizes sampling locations by the Delaunay Method, which is used to remove "redundant" sampling locations from the monitoring network. The detailed discussion of the Delaunay Method is given in Appendix A.2.

Sampling Frequency Determination

Determines the sampling interval for each sampling location by the Modified CES method. The procedures of the Modified CES method are explained in Appendix A.3.

Main Menu: Returns the user to screen *Main Menu*. Reports on sampling optimization results are available by choosing *MAROS Output* in screen *Main Menu*.

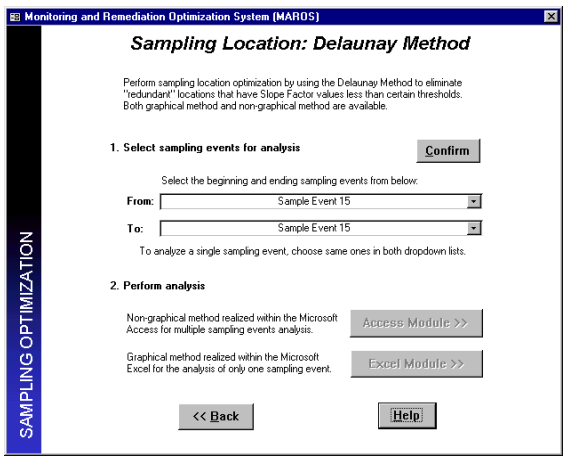
Help: Provides additional information on software operation and screen-specific input requirements.

Steps for use:

1) Select the desired option by clicking the applicable button. The user can choose to run either of them first.
2) When either of the two sub-modules is successfully performed, the corresponding result-report of that sub-module is available (accessed from *Main Menu* by clicking *MAROS Output*).

Sampling Location: Delaunay Method

Sampling Location: Delaunay Method (accessed from screen *Sampling Optimization* by clicking *Sampling Location Determination*) is used to perform sampling location optimization by the Delaunay Method, which is designed to eliminate "redundant" locations from the monitoring network based on analysis of spatial sampling data. Details of the Delaunay Method can be found in Appendix A.2.



Confirm: Confirms the series of continuous sampling events selected by user. The user can also choose to analyze one sampling event.

Access Module: Applies the Delaunay Method built within Microsoft Access to optimize sampling locations.

Excel Module: Applies the Delaunay Method built within Microsoft Excel that has graphical interface and flexible operations. Data are sent to Excel module and results are transferred back. This is applicable to the analysis of only one sampling event.

Back: Returns the user to screen *Sampling Optimization*.

Help: Provides additional information on software operation and screen-specific input requirements.

Steps for use:

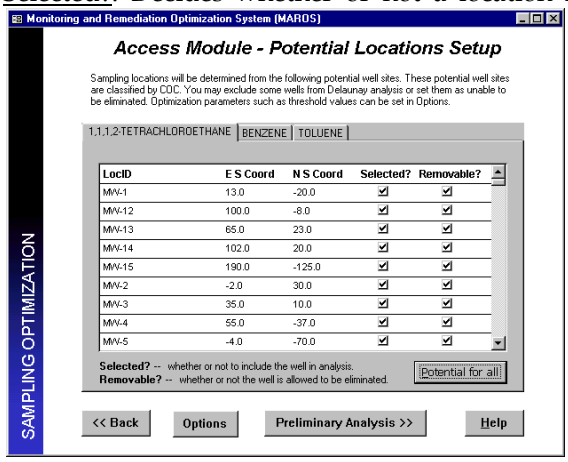
1) Define the sampling events for analysis by selecting from the *From* and *To* combo lists or typing in the names of the sampling events. The *From* sampling event should be no later than the *To* sampling event. If the user wants to analyze one sampling event, this can be done by simply selecting the same sampling event in both combo lists.

Or

1) Use the sampling events already shown (selected in last time) in both combo lists.
2) Click *Confirm* button to confirm the selection. After confirmation, the button *Access Module* will be activated. Button *Excel Module* will be activated only if the sampling events in both *From* and *To* combo lists are the same.
3) Click either *Access Module* or *Excel Module* (if activated) button to perform the analysis.

Access Module – Potential Locations Setup

This screen (accessed from screen *Sampling Location: Delaunay Method* by clicking *Access Module*) is used to set up the properties of potential locations and the options used in the Delaunay Method.



Selected?: Decides whether or not a location is included in the analysis. Check the button to include or uncheck the button to remove this location from the list of potential locations.

Removable?: Decides whether or not a location is allowed to be eliminated by the optimizing process if it is considered as redundant. For example, a sentinel well might be unchecked since it can not be eliminated.

Potential for all: Sets all the sampling locations as potential locations. The *Selected?* status will be set to True for all locations in current COC.

Back: Returns the user to screen *Sampling Location: Delaunay Method*.

Options: Shows screen *Sampling Location Determination – Options*, where the optimization parameters can be set. Otherwise, the default settings or the settings from last time will be used.

Preliminary Analysis: Calculates the sampling-events-averaged Slope Factor (SF) values for all locations in each COC and then proceeds to screen *Access Module – Slope Factor Values*.

Help: Provides additional information on software operation and screen-specific input requirements.

Steps for use:

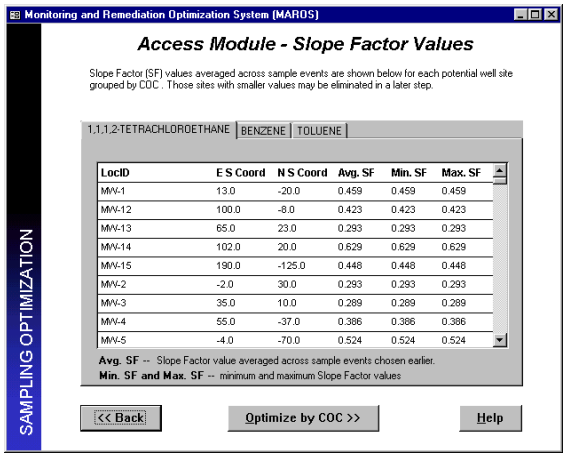
1) Browse sampling locations in each COC by clicking the tab on the page frame, e.g., clicking "TOLUENE" to view sampling locations where TOLUENE concentrations were measured.
2) Remove a location from the potential locations by unselecting the *Selected?* check box. Select *Removable?* check box to decide if a location can be eliminated by the optimizing process.
3) Set up the properties of potential locations for all COCs and then proceed to *Preliminary Analysis*.

During the process, you can click button *Options* to change the optimization parameters that are used by the Delaunay Method. Each COC has its own parameters.

Note: Slope factors in MAROS are an expression of the rate of change in a dataset, and not related to toxicological values for a particular COC (i.e., carcinogenic risk).

Access Module - Slope Factor Values

This screen (accessed from screen *Access Module – Potential Locations Setup* by clicking *Preliminary Analysis*) is used to display the sampling-events-averaged SF values of sampling locations in each COC. The lumped SF value of a location provides a measure of its relative importance to the overall estimation.



Components of viewing:

Avg. SF displays the lumped SF value of a location that is calculated by averaging the SF values obtained in each sampling event across all sampling events selected by the user.

Min. SF displays the minimum SF value of a location obtained from one of the sampling event.

Max. SF displays the maximum SF value of a location obtained from one of the sampling event.

Back: Returns the user to screen *Access Module – Potential Locations Setup*.

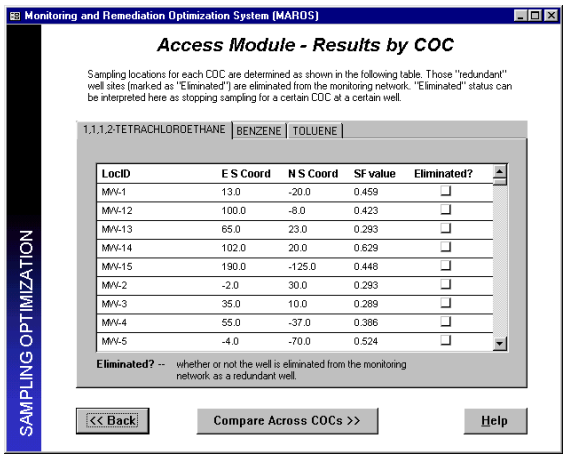
Optimize by COC: Performs optimization for each COC by eliminating redundant sampling locations in each COC and then proceeds to screen *Access Module – Results by COC*.

Help: Provides additional information on software operation and screen-specific input requirements.

Note: Slope factors in MAROS are an expression of the rate of change in a dataset, and not related to toxicological values for a particular COC (i.e., carcinogenic risk).

Access Module - Results by COC

This screen (accessed from screen *Access Module – Slope Factor Values* by clicking *Optimize by COC*) is used to display the sampling location optimization results for each COC. Redundant locations that are eliminated are marked. The remaining locations are unmarked and are recommended for the next round of sampling. Here elimination of a location from a COC only means to stop sampling for that COC at that location, since other COCs may still need to be sampled at his location.



Components of viewing:

SF value displays the lumped SF value of a location that is calculated by averaging the SF values obtained in each sampling event across all sampling events selected by the user.

Eliminated? displays the status of whether or not a location is considered as a redundant one and is eliminated. A check mark in this field stands for the elimination of a location.

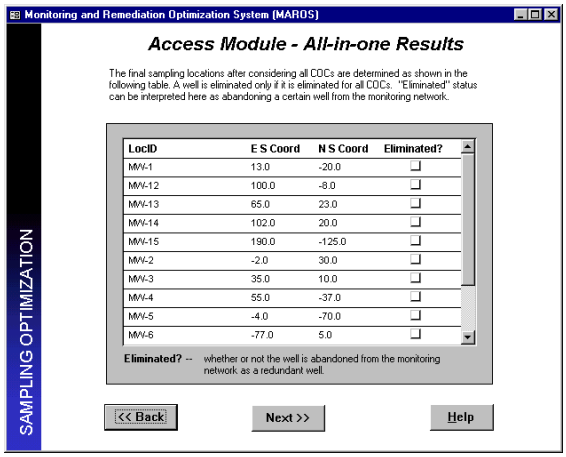
Back: Returns the user to screen *Access Module – Slope Factor Values*.

Compare Across COCs: Determines the conservative all-in-one results by considering all COCs and then proceeds to screen *Access Module – All-in-one Results*.

Help: Provides additional information on software operation and screen-specific input requirements.

Access Module - All-in-one Results

This screen (accessed from screen *Access Module – Results by COC* by clicking *Compare Across COCs*) is used to display the conservative all-in-one sampling location optimization results. A location is marked for elimination only if this location is eliminated from all COCs. Here elimination of a location is equivalent to abandoning this location since no COC needs to be sampled at his location any more.



Components of viewing:

Eliminated? displays the status of whether or not a location is considered as a redundant one and is eliminated. A check mark in this field stands for the elimination of a location.

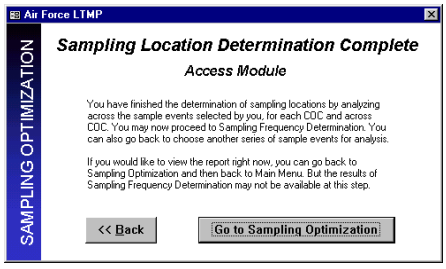
Back: Returns the user to screen *Access Module – Results by COC*.

Next: Proceeds to screen *Sampling Location Determination Complete – Access Module*.

Help: Provides additional information on software operation and screen-specific input requirements.

Sampling Location Determination Complete – Access Module

This screen (accessed from *Access Module – All-in-one Results* by clicking *Next*) is a message screen telling that sampling location determination by the *Access Module* has been completed and the user can go back to proceed other analyses.

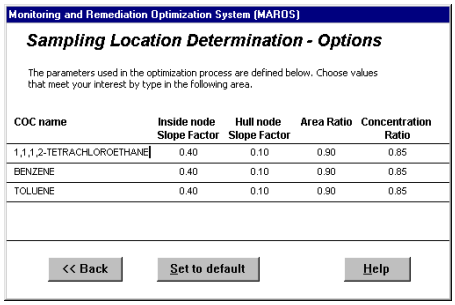


Back: Returns the user to screen *Access Module – All-in-one Results*.

Go to Sampling Optimization: Returns the user to screen *Sampling Optimization*.

Sampling Location Determination - Options

This screen (accessed from screen *Access Module – Potential Locations Setup* by clicking *Options*) is used for setting the optimization parameters (thresholds) that are used by the Delaunay Method. Each COC has its own set of parameters.



These parameters include *Inside node Slope Factor* (SF), *Hull node Slope Factor*, *Area Ratio* (AR), and *Concentration Ratio* (CR). The default values for these parameters are 0.40, 0.10, 0.90 and 0.85, respectively, for all COCs. Detailed explanations of these parameters are referred to Appendix A.2. The user can change parameters by inputting new values in the corresponding fields directly.

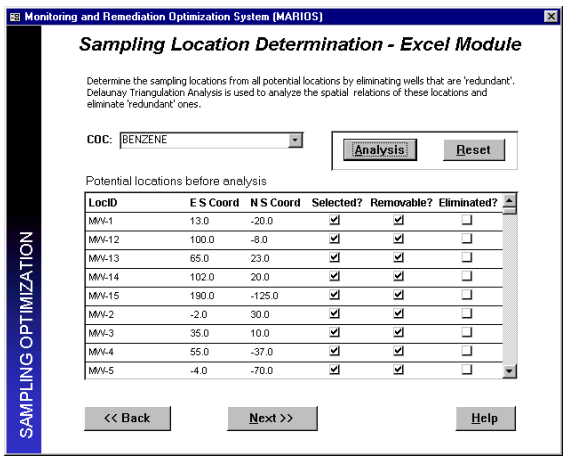
Back: Keeps the changes made by the user and returns the user to screen *Access Module – Potential Locations Setup*.

Set to default: Sets all these parameters for all COC to system default.

Help: Provides additional information on software operation and screen-specific input requirements.

Sampling Location Determination – Excel Module

Sampling Location Determination – Excel Module (accessed from screen *Sampling Location: Delaunay Method* by clicking *Excel Module*) is a control screen for applying the Delaunay Method in a stand alone Microsoft Excel module. It is used for 1) setting up the properties of potential locations; 2) proceeding to the *Excel Module* for optimization; and 3) displaying the results transferred back from the *Excel Module*. The stand alone *Excel Module* "*xlsDelaunay*" will be explained shortly.



The data table is similar to that in the screen *Access Module - Potential Locations Setup*.

COC: Selects the COC you want to analyze from the combo list.

Analysis: Runs *xlsDelaunay*, the Microsoft Excel module. The *xlsDelaunay* worksheet will be opened and becomes the current screen. The analysis is performed for the currently selected COC and for one sampling event only.

Reset: Sets all the sampling locations in a COC as potential locations. The *Selected?* status of each location will be set to True.

Back: Returns the user to screen *Sampling Location: Delaunay Method*.

Next: Proceed to screen *Excel Module – All-in-one Results*.

Help: Provides additional information on software operation and screen-specific input requirements.

Steps for use:

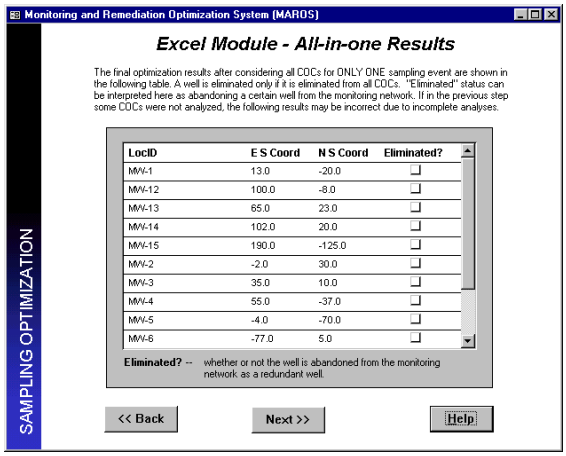
1) Choose the COC for analysis by selecting from the COC combo list or typing in the name.
2) Set the *Selected?* check box of a location to decide if this location is included in the analysis. Set *Removable?* check box to decide if a location can be eliminated by the optimizing process.

Or

2) Set the *Selected?* and *Removable?* status of a location by using Shortcut Menu in worksheet *xlsDelaunay*. This can be performed only when the worksheet *xlsDelaunay* is running.
3) Press button *Analysis* and the screen switches to worksheet *xlsDelaunay*. The data will be transferred to worksheet *xlsDelaunay*.
4) Run worksheet *xlsDelaunay* by following the instructions shown in screen *xlsDelaunay* (discussed shortly).
5) After finishing analysis in worksheet *xlsDelaunay*, send results back by pressing *Back to Access* button. The screen will be switched back and locations that have been eliminated will be shown in field *Eliminated?*. *Selected?* and *Removable?* fields will also be updated if any change has been made in module *xlsDelaunay*.
6) Select other COCs and go back to step 1 until all the COCs have been analyzed.

Excel Module - All-in-one Results

This screen (accessed from screen *Sampling Location Determination – Excel Module* by clicking *Next*) is used to display the all-in-one sampling location optimization results for the analysis of only one sampling event. A location is marked for elimination only if this location is eliminated from all COCs. Here elimination of a location is equivalent to abandoning this location since no COC needs to be sampled at this location any more. If in the previous step some COCs were not analyzed, the results given in this form may be incorrect due to incomplete analyses.



Components of viewing:

Eliminated? displays the status of whether or not a location is considered as a redundant one and is eliminated. A check mark in this field stands for the elimination of a location.

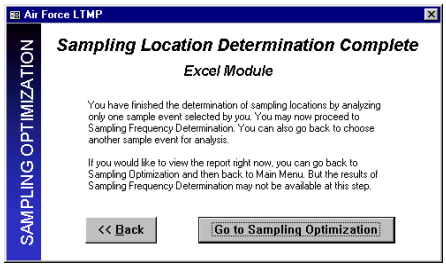
Back: Returns the user to screen *Sampling Location Determination – Excel Module*.

Next: Proceeds to screen *Sampling Location Determination Complete – Excel Module*.

Help: Provides additional information on software operation and screen-specific input requirements.

Sampling Location Determination Complete – Excel Module

This screen (accessed from screen *Excel Module – All-in-one Results* by clicking *Next*) is a message screen telling that the sampling location determination by *Excel Module* has been completed and the user can go back to proceed other analyses.

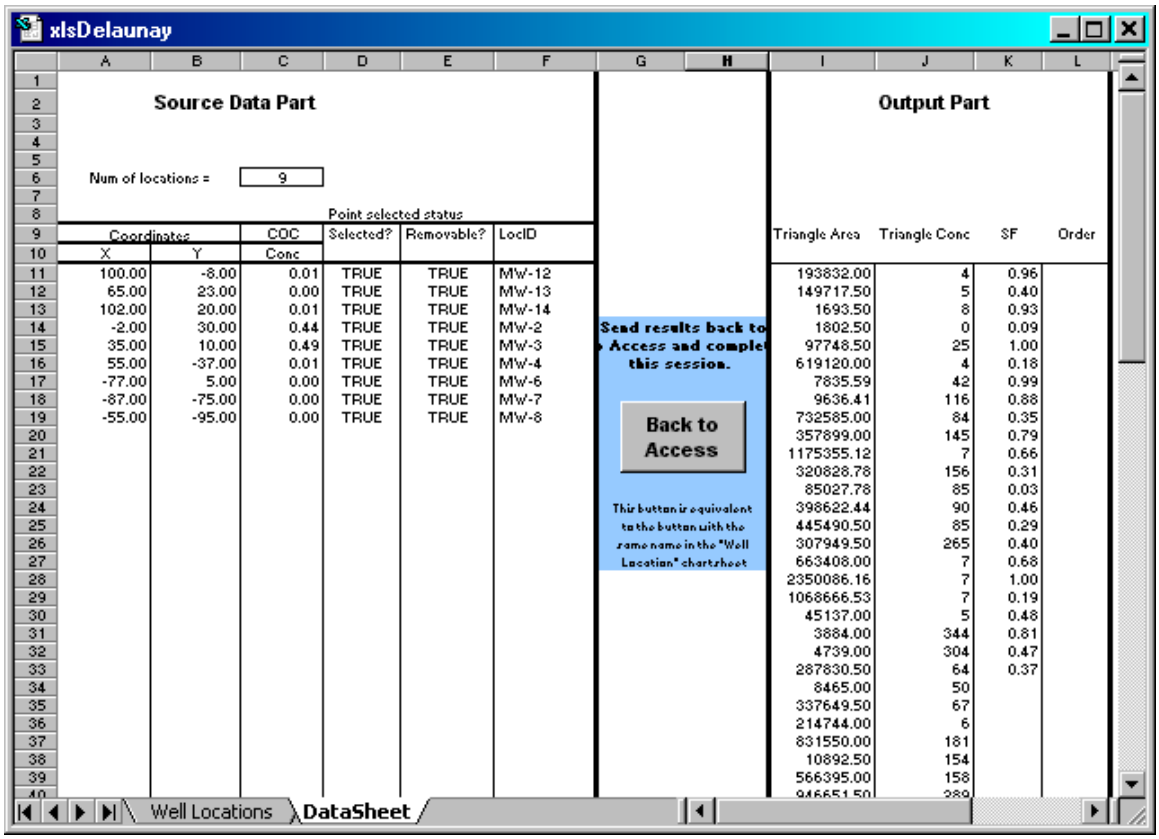


Back: Returns the user to screen *Excel Module – All-in-one Results*.

Go to Sampling Optimization: Returns the user to screen *Sampling Optimization*.

xlsDelaunay

xlsDelaunay (accessed from screen *Sampling Location Determination – Excel Module* by clicking *Analysis*) is a stand-alone Microsoft Excel worksheet used to determine sampling locations by the Delaunay Method. This worksheet contains two parts: the chart-sheet *Well Locations* and the sheet *DataSheet*. The user can click the sheet tab on the lower left corner of the worksheet to switch between the two parts. The *Well Locations* chart sheet is shown on the next page. The figure below is the sheet *DataSheet*.



Back to Access: Sends results back to the Microsoft Access screen *Sampling Location Determination – Excel Module*. The user can also do this by clicking the button with the same name in chart-sheet *Well Locations*.

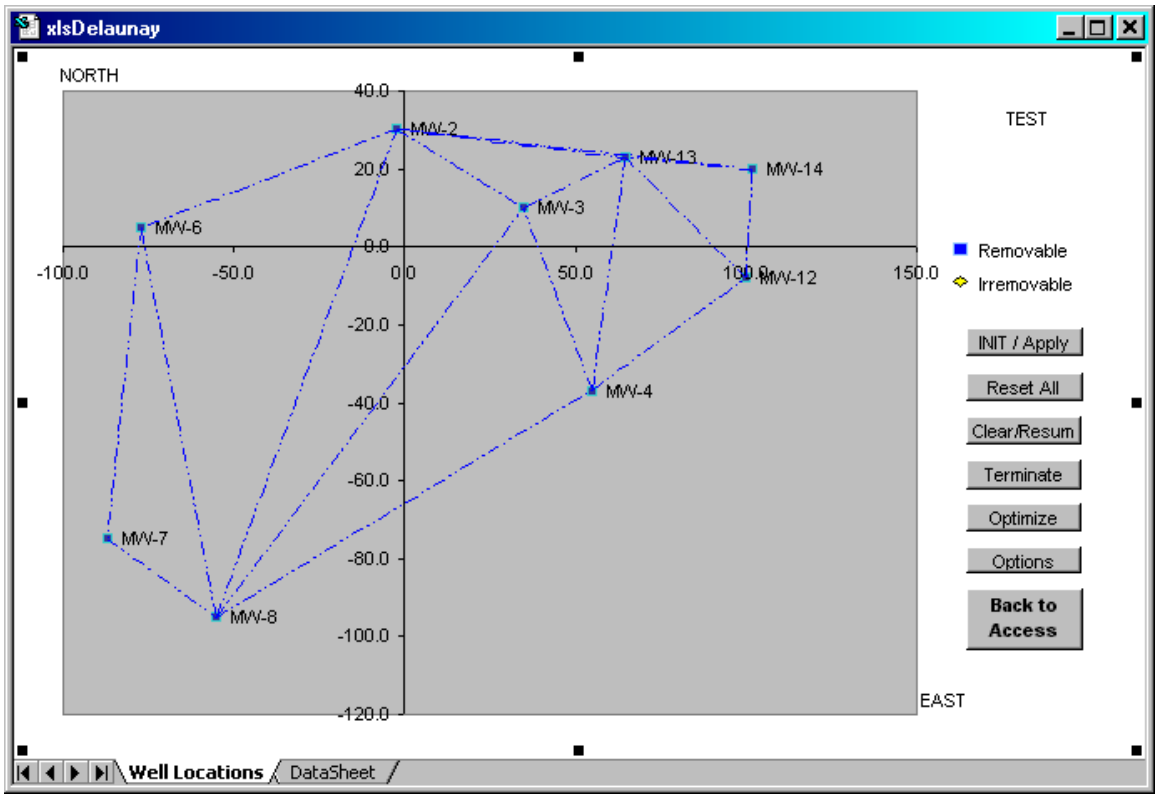
Source Data Part: Stores the data transferred from Microsoft Access.

Output Part: Outputs some of the intermediate results generated during the optimizing process, including the wells eliminated, area ratio and concentration ratio in each optimization step.

WARNING:

Before clicking button *Back to Access*, you should have performed the optimization by using the *Well Locations* chart sheet (see instructions on the next page). Otherwise, the original set of data will be sent back. Do not change anything in this sheet. Furthermore, it is recommended that the user operate in the chart-sheet *Well Locations* instead.

The chart-sheet *Well Locations* is shown below. A plot area is located in the center where the sampling locations are plotted in the EAST-NORTH coordinate system (or relative coordinates system). The legend is in the upper right side. The middle right side contains the command buttons used to control the optimization process.



INIT/Apply: Initializes the program in order to begin an analysis. This is a starting point.

Reset All: Allows all potential locations to be selected. This is very helpful when you have eliminated some locations and then want to recover them.

Clear/Resume: To clear/resume all the lines drew on the plot area. It is only a switch for graphic output. Data will not be influenced.

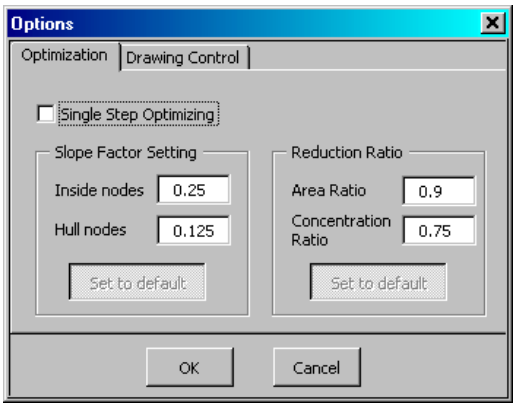
Terminate: Clears memory and stops the program (not to quit the worksheet). If you want to restart an analysis after pressing this button, press *INIT/Apply* again.

Optimize: Performs optimization, i.e., to eliminate "redundant" locations from the potential locations. It can be executed in two ways, the normal way and the single step optimization.

Options: Shows the *Options Form* that includes optimization parameters used in the Delaunay Method and the options for graphic output.

Back to Access: Sends results back to the Microsoft Access screen *Sampling Location Determination – Excel Module*.

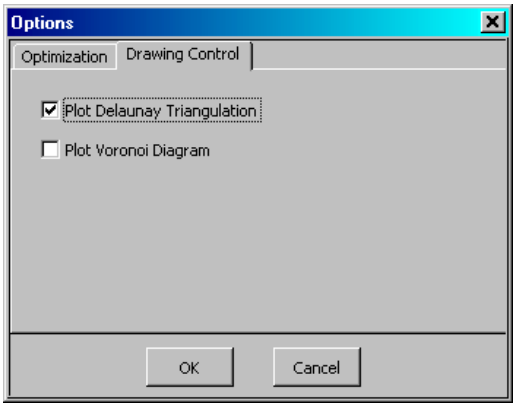
The *Options Form* can only be used in *Well Locations* chart-sheet.



The *Option Form* is assessed by clicking button *Options*. It has two pages.

Shown on the left is the *Optimization* page. Parameters include *Inside node Slope Factor* (SF), *Hull node Slope Factor*, *Area Ratio* (AR), *Concentration Ratio* (CR), and *Single step Optimization*. The default values are same as those in *Access Module*.

Set to default: Sets the parameters to system default. The button will be activated only if the parameter value is not equal to the default value.



Shown on the left is the *Drawing Control* page.

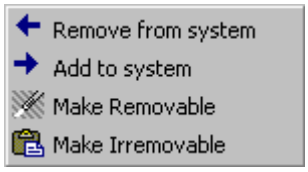
Plot Delaunay Triangulation: By checking this box, the blue triangulation lines will be plotted in the plot area of the chart-sheet.

Plot Voronoi Diagram: By check this box, the Voronoi diagram (or Thiessen polygon) will be plotted in the plot area of the chart-sheet.

Ok: Saves user changes to the parameters and closes this form. The changes will be effective the next time the user performs an optimization. The drawing options will be effective immediately.

Cancel: Cancels user changes and quits the form.

The *Shortcut Menu* allows you to locate a node (location) on the graph and sets its *Selected?* status and *Removale?* status easily. The shortcut menu is available only in the *Well Locations* chart-sheet.



To access the *Shortcut Menu*, clicking left mouse button on a node or the name of the node besides it. And then click again at the same place and the shortcut menu will pop up. The *first click* is just to make sure the data-series has been selected, and the *second click* returns the node information to the program.

Remove from system: Excludes a node from the network by setting *Selected?* status to False.

Add to system: Includes or inserts a node into the network by setting *Selected?* status to True.

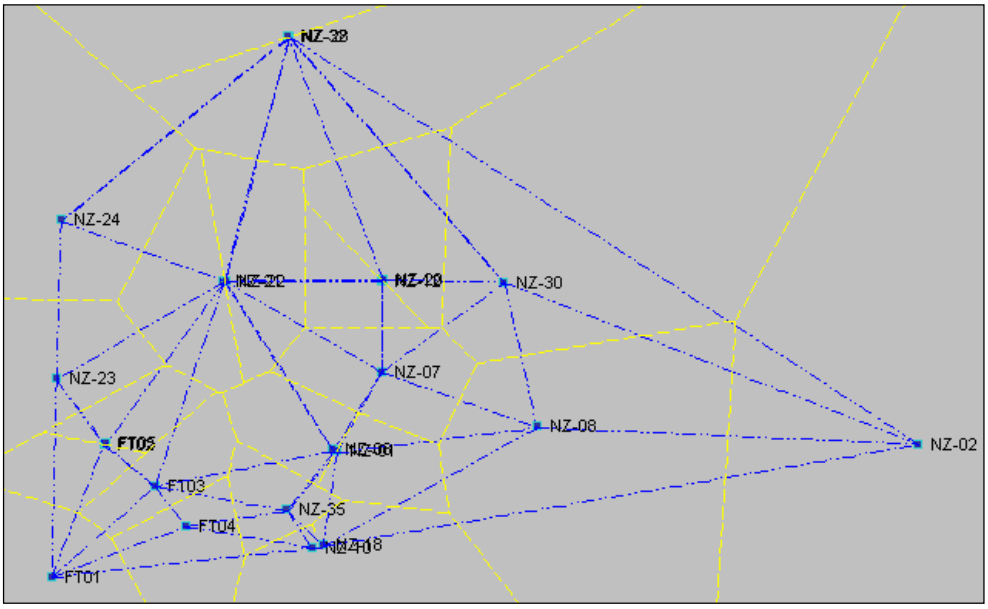
Make Removable: Makes a node removable by setting *Removable?* status to True.

Make Irremovable: Makes a node irremovable by setting *Removable?* status to False.

Steps for use:

1) Start the program (only if it is not automatically loaded) by clicking button *INIT/Apply* in Well Locations chart-sheet. The Delaunay triangles are plotted by default.
2) Set the optimization and drawing control parameters in the *Option Form*. Activate this form by clicking button *Options* in the chart-sheet *Well Locations*. You can neglect this step if you want to use the default parameters.
3) If you do not want to see graphs in the plot area, click button *Clear/Resume* in the chart-sheet *Well Locations* to turn off the graph output. Clicking it again will turn on the graph output. You can also achieve this by deselecting the two drawing parameters in the *Option Form*.
4) If you want to use all locations as potential locations for analysis when some of them have been eliminated, click button *Reset All* in the chart-sheet *Well Locations*. This action will reset the potential locations and redraw the graph.
5) Perform optimization by clicking button *Optimize* in the chart-sheet *Well Locations*. If locations are eliminated from the network, you may notice the change in the graph, if the graph output is turned on.
6) Check the results in the plot area in the chart-sheet *Well Locations* or in the Output Part in the *DataSheet*. If you want to change parameters and run analysis again, go back to step 2.
7) Stop the program by clicking button *Terminate* in the chart-sheet *Well Locations*. Go to step 1 if you need to re-run the optimization.
8) Send results back to Access (screen *Sampling Location Determination – Excel Module*) by clicking button *Back to Access*.

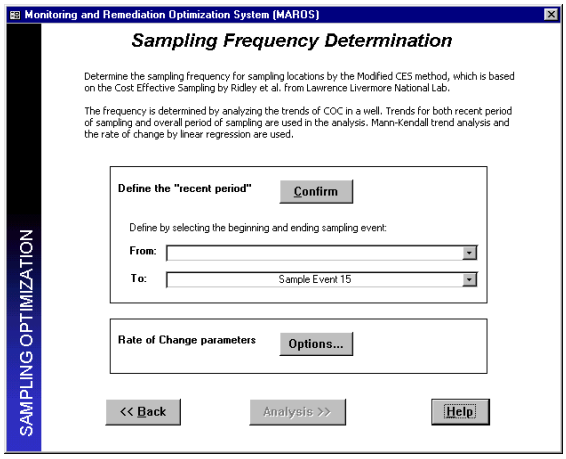
The *xlsDelaunay* worksheet will remain open until the user closes it. All the results and graph output are kept if the user chooses to save the file before closing it. The graph output in the plot area is like the screen shot below:



WARNING: Do not change the name of worksheet *xlsDelaunay* or move it to other folders.

Sampling Frequency Determination

Sampling Frequency Determination (accessed from screen *Sampling Optimization* by clicking *Sampling Frequency Determination*) is used to determine the sampling frequencies at sampling locations. The Modified CES method (adopted from Cost Effective Sampling by Ridley et al. 1998) is applied. This method is based on the analysis of recent trends and long term trends of COCs. The modified CES method aims to reduce sampling frequency based on the analysis of time series sampling data.



The term "recent period" refers to the time period in which the latest series of sampling events happened. It is used to differentiate for example, the latest two years of sampling, from the history of sampling (all sampling events). The "recent period" could contain any series of continuous sampling events ending with the latest sampling event.

From: Selects from the combo list a sampling event as the beginning of the "recent period".

To: Selects a sampling event as the ending of the "recent period".

Confirm: Confirms the "recent period" defined by the user.

Options: Shows the *Sampling Frequency Determination - Options* screen, where the *Rate of Change* parameters for analyzing the concentration trends can be set.

Back: Returns the user to *Sampling Optimization* screen.

Analysis: Determines sampling frequencies at all sampling locations for each COC by using the Modified CES method. The screen *Sampling Frequency Recommendation* will be open and becomes the current screen.

Help: Provides additional information on software operation and screen-specific input requirements.

Steps for use:

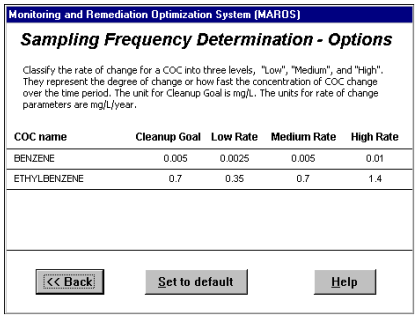
1) Define the "recent period" first. The ending sampling event should be later than the beginning sampling event. At least six sampling events are recommended for analysis. For analysis with less than six samples, the results can not be guaranteed.

Or

1) Use the sampling events shown on the *From* and *To* combo lists (selected in last time).
2) Click *Confirm* button to confirm the selection.
3) Click *Options*, define field specific *Rate of Change* parameters for COCs in that screen. Close that screen and return. If not, the default values will be used.
4) Click *Analysis* to perform the analysis.

Sampling Frequency Determination - Options

This screen (accessed from screen *Sampling Frequency Determination* by clicking *Options*) is used for setting the *Rate of Change* (ROC) parameters that are required by the Modified CES method.



These parameters include *Low Rate*, *Medium Rate* and *High Rate*. Here *Cleanup Goal* (*PRG*: Preliminary Remediation Goal, mg/L) is used as a reference for defining the rate of change parameters. By default, the low rate is defined as 0.5 PRG/year, medium rate is defined as 1.0 PRG/year and high rate is defined as 2.0 PRG/year, for a certain COC. When Cleanup Goal of a COC is not available in the database, the user is prompted to enter the value and the three rate parameters. Otherwise, this COC will not be analyzed. The user should provide specific *Rate of Change* values for a specific field of study, if available. Refer to Appendix A.3 for details.

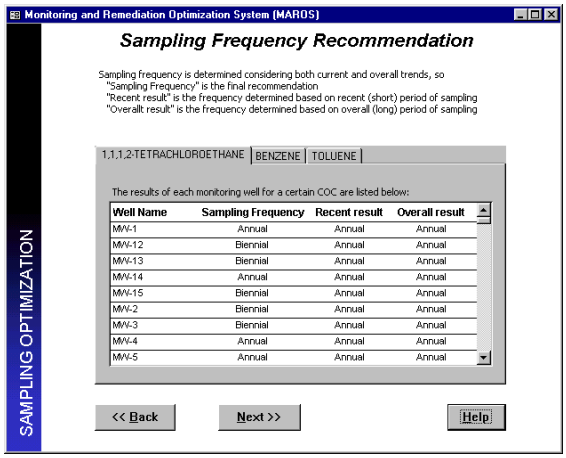
Back: Closes this screen and returns to screen *Sampling Frequency Determination*.

Set to default: Sets all these parameters to system default.

Help: Provides additional information on software operation and screen-specific input requirements.

Sampling Frequency Recommendation

Sampling Frequency Recommendation (accessed from screen *Sampling Frequency Determination* by clicking *Analysis*) is used to display the results of sampling frequency determined by the Modified CES method for all sampling locations for each COC. The information displayed on the screen can also be viewed in report *Sampling Frequency Optimization Report* accessed from screen *MAROS Output* (refer to Appendix A.8 for a sample report).



Select the page with the name of COC to display the recommended results for that COC.

Sampling Frequency: the final frequency recommendation through adjustment of overall trend over recent trend and other factors.

Recent Result: the frequency determined from recent period of data.

Overall Result: the frequency determined from overall period of data.

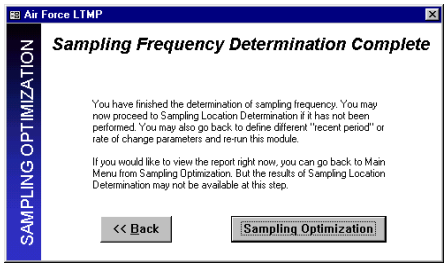
Back: Returns the user to screen *Sampling Frequency Determination*, where the user can change *Rate of Change* parameters and perform a new analysis.

Next: Proceed to screen *Sampling Frequency Determination Complete*.

Help: Provides additional information on software operation and screen-specific input requirements.

Sampling Frequency Determination Complete

This screen (accessed from screen *Sampling Frequency Recommendation* by clicking *Next*) is a message screen telling that sampling frequency determination has been completed and the user can proceed to other analyses.

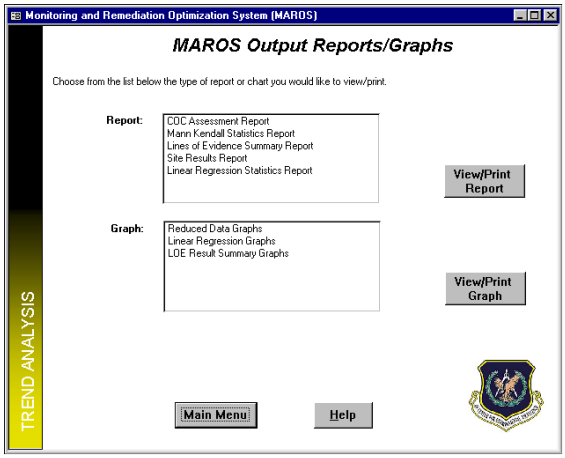


Back: Returns to *Sampling Frequency Recommendation* screen. The user can go back to view the results, or go back step by step to perform a new analysis by changing the *Rate of Change* parameters and redefine the "recent period".

Sampling Optimization: Returns the user to *Sampling Optimization* screen.

MAROS Output Reports

MAROS Output Reports (accessed from the *Main Menu* screen) allows the user to view/print reports and graphs from the site trend analyses as well as a preliminary Site Recommendation Report. Sample Reports are located in Appendix A.8.



View/Print Report: To view/print reports choose the report of interest and click "View/Print Report".

View/Print Graph: To view/print a graph choose the graph of interest and click "View/Print Graph".

Main Menu: Returns the user to the *Main Menu*.

Help: Provides information on the screen-specific input requirements.

LOE Summary Results: Graphing (accessed from the *MAROS Output Reports* screen) allows the user to view/print graphical LOE summary results in Excel.

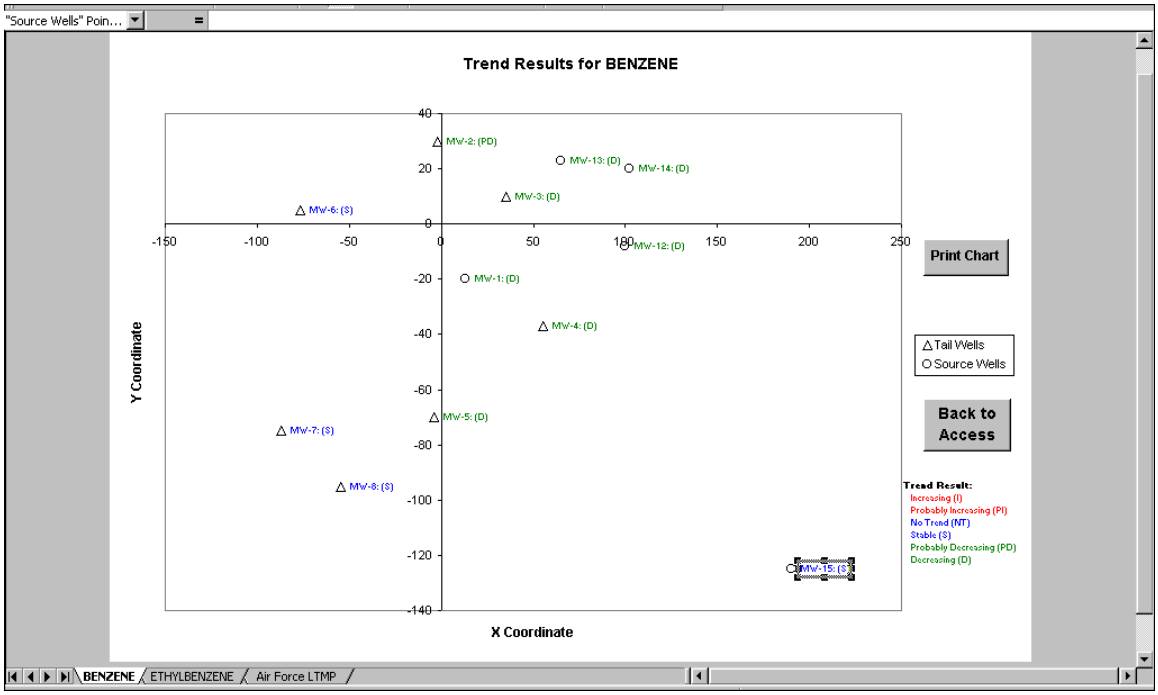
Excel Graph(s): Takes the user to the *Excel Graph* screens.

Back: Returns the user to the *MAROS Output Reports* screen.

Help: Provides information on the screen-specific input requirements.

MAROS Output Reports

LOE Summary Results: Graph (accessed from the *LOE Summary Results: Graphing* screen) allows the user to view/print graphical LOE summary results in Excel. This will open Excel on your computer to provide the trend result graphs.



Excel Graph(s): Takes the user to the *Excel Graph* screens.

Print Chart: Prints the current summary graph.

Back to Access: Returns the user to the *LOE Summary Results: Graphing* screen.

Note: Do not change the name or content of the worksheet *xlsLOETrendResults* or move it to other folders. Also, the *xlsLOETrendResults* worksheet will remain open until the user closes it. All the results and graph output are kept if the user chooses to save the file before closing it. The user should save the file under a different name by choosing "Save as…" under the Excel menu option "File."

DATABASE COMPACTION

To maintain performance, the database must be routinely compacted to remove unused space whenever data is added or changed, using the following procedures.

- Return to the *Main Menu* screen.
- On the "Tool" option of the upper toolbar, select "Database Utilities" and then select "Compact Database".

WARNING: It is good practice to keep a backup copy of the database before compacting. Should the compact process fail, the original database software will still be available.

Initial Database configuration

This software is an automated interface for an Access database containing groundwater data. An experienced Access user can work directly with the database at any time by clicking on the command "F11" or by choosing "Unhide" from the Windows Menu to reveal the Access database ("afcee_MAROS"). The advanced user can use the Access database tools to develop customized queries or reports which provide more detailed analysis and presentation of the dataset.

APPENDICES

A.1. Compliance Monitoring Trend Analysis

A.2. Delaunay Method

A.3. Modified CES Method

A.4. Secondary Line of Evidence: Empirical Data

A.5. MAROS Site Results

A.6. Import File Formats

A.7. Sample Reports

APPENDIX A.1: COMPLIANCE MONITORING TREND ANALYSIS

Authors: Newell, C.J. and Aziz, J.J., Groundwater Services, Inc.

This appendix details the data evaluation and remedy selection procedures employed by the Monitoring and Remediation Optimization System (MAROS) Software. The procedures outlined below were developed to assess appropriate response measures for affected groundwater plumes based on scientifically sound quantitative analyses of current and historical site groundwater conditions.

Initial Site Investigation

Evaluation of groundwater plume conditions and appropriate response measures requires adequate site characterization, including plume delineation. Therefore, for the compliance monitoring evaluation, the minimum required site information includes:

- *Constituents of Concern (COCs):* Individual constituents must be identified along with their relevant source areas and transport mechanisms.
- *Site Hydrogeology:* Site stratigraphy and groundwater flow velocity and direction must be identified.
- *Affected Groundwater:* Plume must be completely delineated for each COC to ensure that the results of the compliance monitoring assessment are reliable and not erroneously influenced by a migrating plume.
- *Time-Series Groundwater Monitoring Data:* Historical record must be compiled for each COC and meet the minimum data requirements described below.
- *Actual and Potential Groundwater Receptors:* Well locations, groundwater-to-surface water discharge locations, underground utilities, or other points of exposure must be identified.
- *Current or Near-Term Impact?:* Any current or near-term receptor impact (defined for this evaluation as occurring in zero to two years) must be assessed. Plumes posing current or near-term impact on applicable receptors are referred for immediate evaluation of appropriate risk management measures.

Site Conceptual Model

The EPA recommends the use of conceptual site models to integrate data and guide both investigative and remedial actions (e.g., see EPA, 1999). A conceptual site model (CSM) is a three-dimensional representation that conveys what is known or suspected about contamination sources, release mechanisms, and the transport and fate of those contaminants. The conceptual model provides the basis for assessing potential remedial technologies at the site. In the context of the MAROS software, conceptual model development prior to software use would allow the user to better utilize the information gained through the various software modules as well as provide guidance for assessing the data that would best typify historical site conditions.

It is recommended that available site characterization data should be used to develop a conceptual model for the site prior to the use of the MAROS software. The conceptual model should include a three-dimensional representation of the source area as a NAPL or region of highly contaminated ground water, of the surrounding uncontaminated area, of ground water flow properties, and of the solute transport system based on available geological, biological, geochemical, hydrological, climatological, and analytical data for the site (EPA, 1998). Data on the contaminant levels and aquifer characteristics should be obtained from wells and boreholes which will provide a clear three-dimensional picture of the hydrologic and geochemical characteristics of the site. High concentrations of dissolved contaminants can be the result of leachates, rinse waters and rupture of water conveyance lines, and are not necessarily associated with NAPLs.

This type of conceptual model differs from the more generic conceptual site models commonly used by risk assessors that qualitatively consider the location of contaminant sources, release mechanisms, transport pathways, exposure points, and receptors. However, the conceptual model of the ground water system facilitates identification of these risk-assessment elements for the exposure pathways analysis. After development, the conceptual model can be used to help determine optimal placement of additional data collection points, as necessary, to aid in the natural attenuation investigation and to develop the solute fate and transport model. Contracting and management controls must be flexible enough to allow for the potential for revisions to the conceptual model and thus the data collection effort.

Successful conceptual model development involves (EPA, 1998):

- Definition of the problem to be solved (generally the three dimensional nature, magnitude, and extent of existing and future contamination).
- Identification of the core or cores of the plume in three dimensions. The core or cores contain the highest concentration of contaminants.
- Integration and presentation of available data, including:
    - Local geologic and topographic maps,
    - Geologic data,
    - Hydraulic data,
    - Biological data,
    - Geochemical data, and
    - Contaminant concentration and distribution data.
- Determination of additional data requirements, including:
    - Vertical profiling locations, boring locations and monitoring well spacing in three dimensions,
    - A sampling and analysis plan (SAP), and
    - Other data requirements.

Conceptual model development prior to use of the MAROS software will allow more accurate site evaluation through quality data input (i.e. identification of source and tail wells, etc.), as well as viewing the MAROS results in light of site-specific conditions. The conceptual model will also allow the user to gain insight into the type and extent of site data that is needed to fulfill minimum data requirements in order to fully utilize the MAROS software.

Minimum Data Requirements

Compliance Monitoring data evaluation must be based on data from a consistent set of wells over a series of periodic sampling events. Statistical validity of the constituent trend analysis requires constraints on the minimum data input. To ensure a meaningful comparison of COC concentrations over time and space, the following minimum requirements were imposed on the time-series groundwater monitoring data:

- *Number of Wells:* Evaluation should include data from at least four wells (ASTM , 1998) in which COCs have been detected. May include up to two wells which have not exhibited COCs during more recent sampling events being analyzed, but in which COCs were previously detected. As many wells should be included in the evaluation as possible, subject to the other minimum data requirements.
- *Minimum Data per Well:* Data for each well should include at least four measured concentrations over six sampling events during the time period being analyzed. For any well, data may not be missing from more than two consecutive sampling events. Guidelines given by ASTM, 1998 notes that a minimum of more than one year of quarterly monitoring data of 4 or 5 wells is needed to establish a trend.
- *Number of Sampling Events:* Evaluation should include at least six most-recent sampling events which satisfy the minimum groundwater data requirements specified above. For this evaluation, it is suggested that the user consolidate multiple sampling dates within a single quarter to consider them to be a single sampling event, with multiple measurements of the same constituent subject to a user defined consolidation (e.g. average). The sampling events do not need to be the same for each well.

Sufficient Data: At least four wells with four or more independent sampling events per well are available

Insufficient Data: Fewer than four wells or fewer than 4 independent sampling events per well are available.

Although the software will calculate trends for fewer than four wells and a minimum of 4 sampling events, the above criteria will ensure a meaningful evaluation of COC trends over time. The minimum requirements described would apply only to "well behaved" sites, for most sites more data is required to obtain an accurate representation of COC trends. Sites with significant variability in groundwater monitoring data (due to water table fluctuation, variations in groundwater flow direction, etc.) will require more data to obtain meaningful stability trends. Essentially, the plume you are evaluating should be delineated with adequate consecutive sampling data to accurately evaluate the concentration trend with time.

Plume Stability Analysis

Confirmation of the effective performance of monitored natural attenuation as a stand-alone remedial measure requires the demonstration of *primary lines of evidence,* i.e., actual measurement of stable or shrinking plume conditions based on evaluation of historical groundwater monitoring data. For a delineated plume, a stable or shrinking condition can be identified by a stable or decreasing concentration trends over time. For this analysis, an overall plume condition was determined for each COC based on a statistical trend analysis of concentrations at each well, as described below.

STATISTICAL TREND ANALYSIS: CONCENTRATION VS. TIME

Under optimal conditions, the natural attenuation of organic COCs at any site is expected to approximate a first-order exponential decay for compliance monitoring groundwater data. With actual site measurements, apparent concentration trends may often be obscured by data scatter arising from non-ideal hydrogeologic conditions, sampling and analysis conditions. However, even though the scatter may be of such magnitude as to yield a poor goodness of fit (typically characterized by a low correlation coefficient, e.g., $R^2 \ll 1$) for the first-order relationship, parametric and nonparametric methods can be utilized to obtain *confidence intervals* on the estimated first-order coefficient, i.e., the slope of the log-transformed data.

Nonparametric tests such as the Mann-Kendall test for trend are suitable for analyzing data that do not follow a normal distribution. Nonparametric methods focus on the location of the probability distribution of the sampled population, rather than specific parameters of the population. The outcome of the test is not determined by the overall magnitude of the data points, but depends on the ranking of individual data points. Assumptions on the distribution of the data are not necessary for nonparametric tests. The Mann-Kendall test for trend is a nonparametric test which has no distributional assumptions and irregularly spaced measurement periods are permitted. The advantage gained by this approach involves the cases where outliers in the data would produce biased estimates of the least squares estimated slope. Parametric tests such as first-order regression analysis make assumptions on the normality of the data distribution, allowing results to be affected by outliers in the data in some cases. However, the advantage of parametric methods involve more accurate trend assessments result from data where there is a normal distribution of the residuals. Therefore, when the data is normally distributed the nonparametric method, the Mann-Kendall test, is not as efficient. Both tests are utilized in the MAROS software.

Primary Line of Evidence 1: Mann-Kendall Analysis

GENERAL

The Mann-Kendall test is a non-parametric statistical procedure that is well suited for analyzing trends in data over time (Gilbert, 1987). The Mann-Kendall test can be viewed as a nonparametric test for zero slope of the first-order regression of time-ordered concentration data versus time. The AFCEE MAROS Tool includes this test to assist in the analysis of groundwater plume stability. The Mann-Kendall test does not require any assumptions as to the statistical distribution of the data (e.g. normal, log-normal, etc.) and can be used with data sets which include irregular sampling intervals and missing data. The Mann-Kendall test is designed for analyzing a single groundwater constituent, multiple constituents are analyzed separately.

For this evaluation, a decision matrix was used to determine the "Concentration Trend" category for each well, as presented on Table 2.

MANN-KENDALL STATISTIC (S)

The Mann-Kendall statistic (S) measures the trend in the data. Positive values indicate an increase in constituent concentrations over time, whereas negative values indicate a decrease in constituent concentrations over time. The strength of the trend is proportional to the magnitude of the Mann-Kendall Statistic (i.e., large magnitudes indicate a strong trend).

Data for performing the Mann-Kendall Analysis should be in time sequential order. The first step is to determine the sign of the difference between consecutive sample results. $Sgn(x_j - x_k)$ is an

indicator function that results in the values 1, 0, or –1 according to the sign of $x_j - x_k$ where j > k, the function is calculated as follows

$\text{sgn}(x_j - x_k) = 1$ if $x_j - x_k > 0$

$\text{sgn}(x_j - x_k) = 0$ if $x_j - x_k = 0$

$\text{sgn}(x_j - x_k) = -1$ if $x_j - x_k < 0$

The Mann-Kendall statistic (S) is defined as the sum of the number of positive differences minus the number of negative differences or

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} \text{sgn}\left(x_j - x_k\right).$$

The confidence on the Mann-Kendall statistic can be measured by assessing the S result along with the number of samples, n, to find the confidence in the trend by utilizing a Kendall probability table found in many statistical textbooks (e.g. Hollander, M. and Wolfe, D.A., 1973). The resulting confidence in the trend is applied in the Mann Kendall trend analysis as outlined in Table A.1.1. The Mann-Kendall test is limited to 40 sample events.

AVERAGE

The arithmetic mean of a sample of n values of a variable is the average of all the sample values written as

$$\bar{x} = \frac{\sum_{i=1}^{n} x_i}{n}$$

STANDARD DEVIATION

The standard deviation is the square root of the average of the square of the deviations from the sample mean written as

$$s = \sqrt{\frac{\sum_{i=1}^{n} \left(x_i - \bar{x}\right)^2}{n-1}}.$$

The standard deviation is a measure of how the value fluctuates about the arithmetic mean of the data.

COEFFICIENT OF VARIATION (COV)

The Coefficient of Variation (COV) is a statistical measure of how the individual data points vary about the mean value. The coefficient of variation, defined as the standard deviation divided by the average or

$$C.O.V. = \frac{s}{\bar{x}}$$

Values less than or near 1.00 indicate that the data form a relatively close group about the mean value. Values larger than 1.00 indicate that the data show a greater degree of scatter about the mean.

RESULTS AND INTERPRETATION OF RESULTS: MANN-KENDALL ANALYSIS

The Constituent Trend Analysis results are presented in the *Mann-Kendall Analysis* Screen (accessed from the *Trend Analysis Menu*). The software uses the input data to calculate the Coefficient of Variation (COV) and the Mann-Kendall statistic (S) for each well with at least four sampling events (see Figure A.11). A "Concentration Trend" and "Confidence in Trend" are reported for each well with at least four sampling events. If there is insufficient data for the well trend analysis, N/A (Not Applicable) will be displayed in the "Concentration Trend" column.

BENZENE | ETHYLBENZENE | 1,2-DICHLOROBENZENE | TOLUENE | XYLENES, TOTAL

Statistical Analysis Results. Last column is the result for the trend.

Well	S/T	COV	MK (S)	Confidence in Trend	Concentration Trend
MW-8	S	0.985	-11	70.50%	S
MW-7	S	0.249	-7	62.60%	S
MW-14	S	1.606	-50	99.90%	D
MW-13	S	1.106	-53	99.80%	D
MW-12	S	1.591	-68	100.00%	D
MW-1	S	1.701	-15	98.50%	D
MW-6	T	0.000	0	47.80%	S
MW-5	T	0.851	-31	99.80%	D

Note: Increasing (I); Probably Increasing (PI); Stable (S); Probably Decreasing (PD); Decreasing (D); No Trend (NT); Not Applicable (N/A); Source/Tail (S/T); COV (Coefficient of Variation); MK(S) Mann-Kendall Statistic

FIGURE A.1.1 MANN-KENDALL ANALYSIS RESULTS

- The Coefficient of Variation (COV) is a statistical measure of how the individual data points vary about the mean value. Values less than or near 1.00 indicate that the data form a relatively close group about the mean value. Values larger than 1.00 indicate that the data show a greater degree of scatter about the mean.
- The Mann-Kendall statistic (MK (S) measures the trend in the data. Positive values indicate an increase in constituent concentrations over time, whereas negative values indicate a decrease in constituent concentrations over time. The strength of the trend is proportional to the magnitude of the Mann-Kendall Statistic (i.e., large magnitudes indicate a strong trend).
- The "Confidence in Trend" is the statistical confidence that the constituent concentration is increasing (S>0) or decreasing (S<0).
- The "Concentration Trend" for each well is determined according to the following rules, where COV is the coefficient of variation:

TABLE A.1.1 MAROS MANN-KENDALL ANALYSIS DECISION MATRIX

Mann-Kendall Statistic	Confidence in Trend	Concentration Trend
S > 0	> 95%	Increasing
S > 0	90 - 95%	Probably Increasing
S > 0	< 90%	No Trend
S ≤ 0	< 90% and COV ≥ 1	No Trend
S ≤ 0	< 90% and COV < 1	Stable
S < 0	90 - 95%	Probably Decreasing
S < 0	95%	Decreasing

The MAROS Mann-Kendall Analysis Decision Matrix was developed in-house by Groundwater Services Inc. The user can choose not to apply one of the two primary lines of evidence decision matrices. Choose "Not Used" in the Lines of Evidence (LOE) weighting screen. If the user would like to use another decision matrix to determine stability of the plume, they would need to do this outside the software.

Primary Lines of Evidence 2: Linear Regression Analysis

GENERAL

Linear Regression is a parametric statistical procedure that is typically used for analyzing trends in data over time. However, with the usual approach of interpreting the log slope of the regression line, concentration trends may often be obscured by data scatter arising from non-ideal hydrogeologic conditions, sampling and analysis conditions, etc. Even though the scatter may be of such magnitude as to yield a poor goodness of fit (typically characterized by a low correlation coefficient, e.g., $R^2 \ll 1$) for the first-order relationship, *confidence intervals* can nonetheless be constructed on the estimated first-order coefficient, i.e., the slope of the log-transformed data. Using this type of analysis, a higher degree of scatter simply corresponds to a wider confidence interval about the average log-slope. Assuming the *sign* (i.e., positive or negative) of the estimated log-slope is correct, a level of confidence that the slope is not zero can be easily determined. Thus, despite a poor goodness of fit, the overall *trend* in the data may still be ascertained, where low levels of confidence correspond to "Stable" or "No Trend" conditions (depending on the degree of scatter) and higher levels of confidence indicate the stronger likelihood of a trend. The coefficient of variation, defined as the standard deviation divided by the average, is used as a secondary measure of scatter to distinguish between "Stable" or "No Trend" conditions for negative slopes. The Linear Regression Analysis is designed for analyzing a single groundwater constituent, multiple constituents are analyzed separately. The MAROS software includes this test to assist in the analysis of groundwater plume stability.

For this evaluation, a decision matrix was used to determine the "Concentration Trend" category for each well, as presented on Table A.1.2.

LINEAR REGRESSION

The objective of linear regression analysis is to find the trend in the data through the estimation of the log slope as well as placing confidence limits on the log slope of the trend. Regression begins with the specification of a model to be fitted. A linear relationship is one expressed by a linear equation. The Linear Regression analysis in MAROS is performed on Ln (COC Concentration) versus Time. The regression model assumes that for a fixed value of x (sample date) the expected value of y (log COC concentration) is some function. For a particular value, x_i or sample date the predicted value for y (log COC concentration) is given by

$$\hat{y}_i = a + bx_i .$$

The fit of the predicted values to the observed values (x_i, y_i) are summarized by the difference between the observed value y_i and the predicted value $\hat{y}_i$ (the residual value.) A reasonable fit to the line is found by making the residual values as small as possible. The method of least squares is used to obtain estimates of the model parameters (a, b) that minimize the sum of the squared residuals, S^2 or the measure of the distance between the estimate and the values we want to predict (the y's).

$$S^2 = \sum_{i=1}^{n} (y_i - \hat{y}_i)^2$$

The values for the intercept (a) and the slope (b) of the line that minimize the sum of the squared residuals (S^2), are given by

$$b = \frac{\sum_{i=1}^{n} (x_i - \bar{x})(y_i - \bar{y})}{\sum_{i=1}^{n} (x_i - \bar{x})^2} \qquad \text{and} \qquad a = \bar{y} - b\bar{x}$$

where $\bar{x}$ and $\bar{y}$ are the mean x and y (log COC concentration) values in the dataset.

In order to test the confidence on the regression trend, there is a need to place confidence limits on the slope of the regression line. In this stage of the trend analysis, it is assumed that for each x value, the y-distribution is normal. A t-test may be used to test that the true slope is different from zero. This t-test is preferentially used on data that is not serially correlated or seasonally cyclic or skewed.

The variance of y_i (σ^2) is estimated by the quantity $S^2_{y.x}$ where this quantity is defined as

$$S^2_{y.x} = \frac{\sum_{i-1}^{n} (y_i - \hat{y}_i)^2}{n-2}$$

where n is the number of samples.

The estimation of the standard deviation or standard error of the slope (s.e.b.) is defined as

$$s.e.b. = \frac{S_{x.y}^2}{\sum_{i-1}^{n}(x_i - \bar{x}_i)^2}.$$

To test significance of the slope calculated, the following t-test result can be used to find the confidence interval for the slope.

$$t = \frac{b}{s.e.b.}$$

The t result along with the degrees of freedom (n-2) are used to find the confidence in the trend by utilizing a t-distribution table found in most statistical textbooks (e.g. Fisher, L.D. and van Belle, G., 1993). The resulting confidence in the trend is utilized in the linear regression trend analysis as outlined in Table A.1.2.

RESULTS AND INTERPRETATION OF RESULTS: LINEAR REGRESSION ANALYSIS

The Constituent Trend Analysis Results are presented in the Linear Regression Analysis Screen (accessed from the Mann-Kendall Analysis screen). The software uses the input data to calculate the Coefficient of Variation (COV) and the first-order coefficient (Ln Slope) for each well with at least four sampling events. A "Concentration Trend" and "Confidence in Trend" are reported for each well with at least four sampling events. If there is insufficient data for the well trend analysis, N/A (Not Applicable) will be displayed in the "Concentration Trend" column (Figure A.1.2)

BENZENE | ETHYLBENZENE | 1,2-DICHLOROBENZENE | TOLUENE | XYLENES, TOTAL

Statistical Analysis Results. Last column is the result for the trend.

Well	S/T	Average	Ln Slope	COV	Confidence in Trend	Concentration Trend
MW-8	S	6.8E-04	-9.5E-05	9.8E-01	82.2%	S
MW-7	S	5.4E-04	-3.1E-05	2.5E-01	78.1%	S
MW-14	S	9.5E-03	-1.0E-03	1.6E+00	99.6%	D
MW-13	S	1.7E-02	-1.5E-03	1.1E+00	100.0%	D
MW-12	S	3.6E-02	-1.7E-03	1.6E+00	100.0%	D
MW-1	S	3.6E-01	-1.4E-03	1.7E+00	99.6%	D
MW-6	T	5.0E-04	0.0E+00	0.0E+00	100.0%	S

Note: Increasing (I); Probably Increasing (PI); Stable (S); Probably Decreasing (PD); Decreasing (D); No Trend (NT); Not Applicable (N/A); Source/Tail (S/T); COV (Coefficient of Variation)

FIGURE A.1.2 LINEAR REGRESSION ANALYSIS RESULTS

- The Coefficient of Variation (COV) is a statistical measure of how the individual data points vary about the mean value. Values less than or near 1.00 indicate that the data form a relatively close group about the mean value. Values larger than 1.00 indicate that the data show a greater degree of scatter about the mean.

- The Log Slope (Ln Slope) measures the trend in the data. Positive values indicate an increase in constituent concentrations over time, whereas negative values indicate a decrease in constituent concentrations over time.
- The "Confidence in Trend" is the statistical confidence that the constituent concentration is increasing (ln slope>0) or decreasing (ln slope<0).
- The "Concentration Trend" for each well is determined according to the following rules, where COV is the coefficient of variation:

TABLE A.1.2 MAROS LINEAR REGRESSION ANALYSIS DECISION MATRIX

Confidence in Trend	Ln Slope	
	Positive	Negative
<90%	No Trend	*COV < 1* Stable *COV > 1* No Trend
90% – 95%	Probably Increasing	Probably Decreasing
> 95%	Increasing	Decreasing

COV = Coefficient of Variation

The MAROS Linear Regression Analysis Decision Matrix was developed in-house by Groundwater Services Inc. The user can choose not to apply one of the two primary lines of evidence decision matrices. Choose "Not Used" in the Lines of Evidence (LOE) weighting screen. If the user would like to use another decision matrix to determine stability of the plume, they would need to do this outside the software.

Further Considerations

The results of a constituent concentration trend analysis form just one component of a plume stability analysis. Additional considerations in determining the over-all plume stability include:

- Multiple constituent concentration trend analyses
- Adequate delineation of the plume
- Proximity of monitoring wells with stable or decreasing constituent trends to the downgradient edge of the plume

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APPENDIX A.2 — DELAUNAY METHOD

Authors: Ling, M. and Rifai, H. S., University of Houston.

This section explains the approach developed by the authors in the MAROS software system for the determination of sampling locations, the so-called **Delaunay Method**. Delaunay Method is designed to select the minimum number of sampling locations based on the spatial analysis of the relative importance of each sampling location in the monitoring network. The approach allows elimination of sampling locations that have little statistical impact on the historical characterization of a contaminant plume. In this version of MAROS, the Delaunay Method is in fact an optimization approach that deals with the reduction of redundancy only.

Theoretical Basis

Delaunay Method is developed based on Delaunay triangulation, which is the triangulation of a point set with the property that no point in the point set falls in the interior of the circumcircle of any triangle in the triangulation. As seen in FIGURE A.2.1, all nodes (potential well locations) are joined by the blue lines, which form the edges of Delaunay triangles. The yellow lines form a lot of polygons called Thiessen polygons or Voronoi diagrams, which are the dual parts of Delaunay triangles.

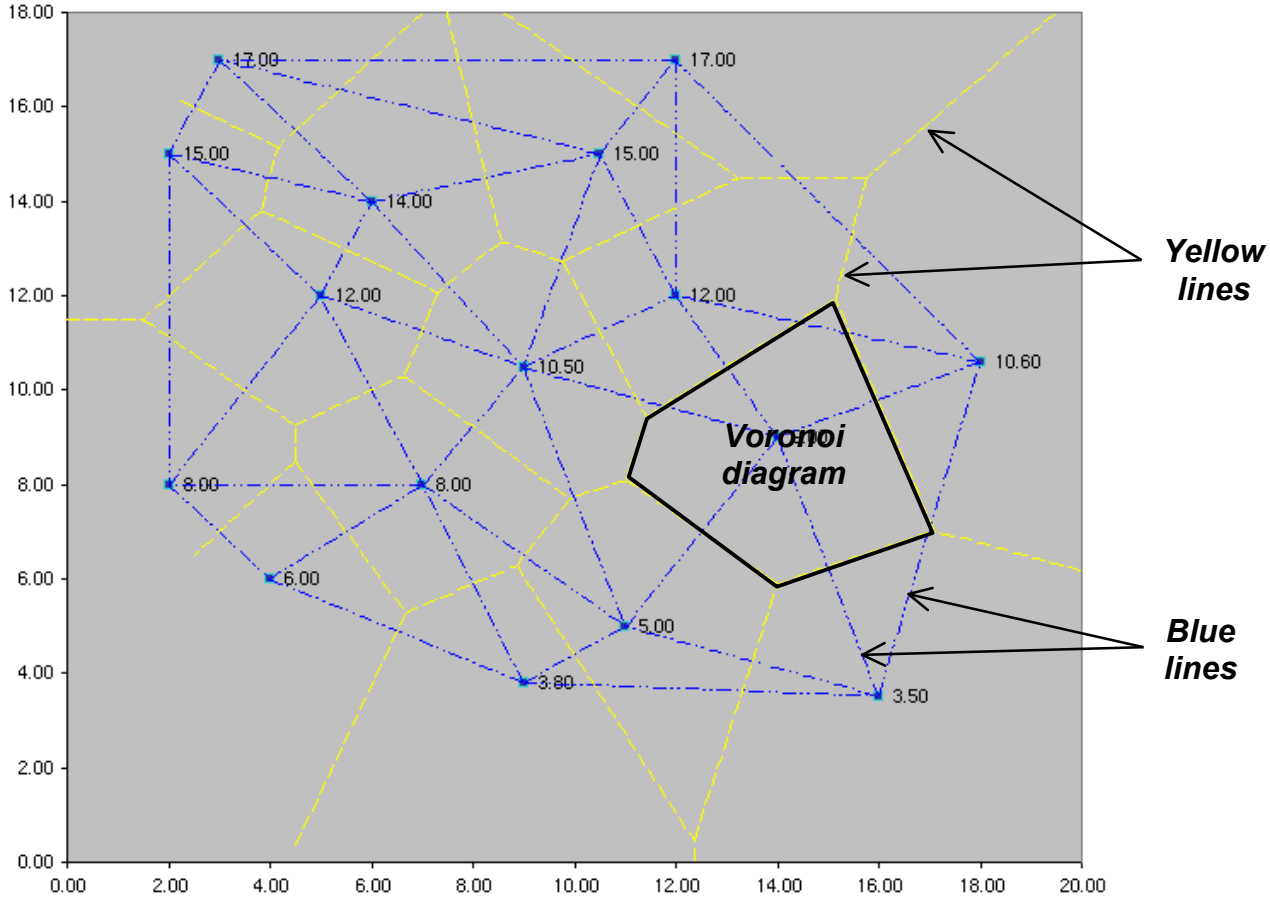


FIGURE A.2.1 ILLUSTRATION OF DELAUNAY TRAIANGULATION

Delaunay triangles and Voronoi diagrams have been widely used for centuries for solving spatial distribution problems (Okabe et al. 1992, Watson 1994). In MAROS, Delaunay triangulation is first used to generate a grid for the studied site with potential sampling locations as its nodes. Then based on the formation of Delaunay triangles and Voronoi diagrams, spatial analyses are made to determine the relative importance of each sampling location. Finally, spatial-redundant locations are eliminated from the monitoring network.

To determine the relative importance of potential locations in the monitoring network, we define Slope Factor (SF) for each potential location to measure the information conveyed by each of them. The SF of a location is defined as the standardized difference between the logarithmic scales of its measured concentration and its estimated concentration. Since the spatial distribution of groundwater quality data tends to follow lognormal distribution, using logarithmic scale of the concentrations will make the plume surface more smoothly. Using logarithmic transformations of the concentrations for estimating the average plume concentration were seen in some studies (Rice et al. 1995; Mace et al. 1997). To be consistent, the SF calculation is thus based on the logarithmic scale of the concentrations. The following steps are used to calculate SF.

1) For a given node N_0, find its natural neighbors N_i, i.e., the set of nodes that are directly connected to this node by an edge of a Delaunay triangle (FIGURE A.2.2).

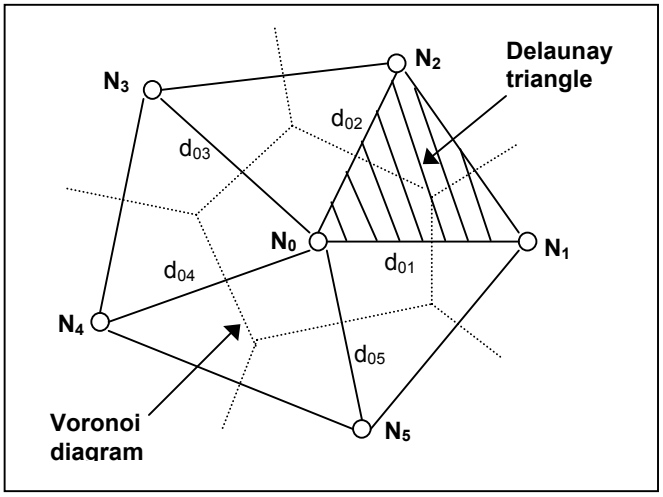


FIGURE A.2.2 ILLUSTRATION OF NATURAL NEIGHBORS

2) The estimated logarithmic concentration EC_0 of node N_0 is computed as the inverse-distance-weighted average of logarithmic concentrations of its natural neighbors:

$$EC_0 = \sum_{i=1}^{n}\left(NC_i \cdot \frac{1}{d_{oi}} \right) \Big/ \sum_{i=1}^{n} \frac{1}{d_{oi}}$$

where:

n = number of natural neighbors

NC_i = measured concentration in logarithmic scale at node N_i, $i = 1, 2, \ldots, n$

d_{0i} = distance between node N_0 and its natural neighbor N_i

3) The SF is then calculated as:

$$SF = \left| \frac{EC_0 - NC_0}{Max(EC_0, NC_0)} \right|$$

where:

EC0 = estimated logarithmic concentration at node N0

NC0 = measured concentration in logarithmic scale at node N0

The magnitude of SF ranges from 0 to 1 (not including 1). Value 0 means that the concentration at a location can be exactly estimated by its surrounding locations, thus, sampling at this location provides no extra information to our knowledge of the plume. A value larger than 0 indicates the existence of estimation error. The larger is the estimation error, the larger the discrepancy would be between the estimated concentration and the measured concentration at a location. Consequently, it becomes more reasonable to keep sampling at this location so that the plume can be better defined. In summary, the larger the SF value of a location is, the more important is this location and vice versa.

Our objectives in spatial sampling are to accurately map a contaminant plume and track the change in this plume. It is clear that with more monitoring wells these can be achieved in a higher degree of accuracy. Unfortunately, there is always a trade-off between degree of accuracy and budget. The limitation of resources forces us to find a way to use as few monitoring wells as possible as far as certain degree of accuracy can be kept (no significant information loss).

To ensure that the elimination of sampling locations from monitoring network will not cause significant information loss, two indicators are developed to measure the information loss. One is Average Concentration Ratio (CR) and the other is Area Ratio (AR), which are defined as:

$$CR = \frac{C_{avr,Current}}{C_{avr,Original}} \qquad AR = \frac{A_{Current}}{A_{Original}}$$

where:

$C_{avr,Current}$ = average plume concentration estimated after elimination of locations in the current step of optimization

$C_{avr,Original}$ = average plume concentration estimated from the potential locations (before elimination of any locations)

$A_{Current}$ = Triangulation area based on locations after elimination of locations in the current step of optimization

$A_{Original}$ = Triangulation area based on potential locations before any optimization (before elimination of any locations)

The average plume concentration is taken as the area-weighted average of the average concentrations of all Delaunay triangles:

$$C_{avr} = \sum_{i=1}^{N} TC_i \cdot TA_i \Big/ \sum_{i=1}^{N} TA_i$$

where:

N = number of all Delaunay triangles in the triangulation

TA_j = area of each Delaunay triangle, $i = 1, 2, \ldots, N$

TC_i = average concentration of each Delaunay triangle, $i = 1, 2, \ldots, N$

TC_i is computed as (refer to FIGURE A.2.3):

$$TC_i = \frac{NC_1 \cdot A_1 + NC_2 \cdot A_2 + NC_3 \cdot A_3}{A_1 + A_2 + A_3}$$

where:

NC_1 = logarithmic concentration at node NC_1

NC_2 = logarithmic concentration at node NC_2

NC_3 = logarithmic concentration at node NC_3

A_1 = *Area of sub-part* A_1

A_2 = *Area of sub-part* A_2

A_3 = *Area of sub-part* A_3

After elimination of "unimportant" locations (those with smallest SF values), the estimation of average plume concentration and triangulation area might be affected. By judging the values of CR and AR, information loss can be evaluated. CR and AR values close to 1 indicate that the information about the plume after elimination of locations is well kept. CR and AR values closing to 0 represent a large estimation discrepancy and thus indicate greater information loss. By setting the acceptable level of information loss, we can judge when to stop eliminating locations. Those eliminated locations are called "redundant" locations and the rest of potential locations are non-redundant ones and should be kept. An interpretation of the above decision process is given in FIGURE A.2.4.

The optimization process is iterative. It starts by eliminating the location(s) with smallest SF value(s), then followed by a check of information loss. If information loss is not significant (within the acceptable range), repeat the process until significant information loss happens. There are two choices to perform the optimization: 1) eliminating one location (the one with smallest SF) at a step, and 2) eliminating many locations (the ones with SF values less than a threshold) at a step. The first choice is named *Single Step* optimization.

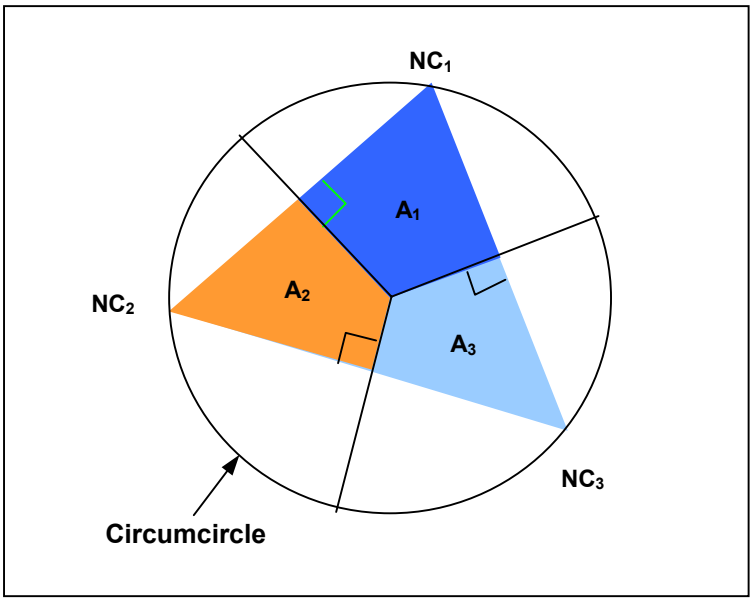


FIGURE A.2.3 DIVISION OF A DELAUNAY TRIANGLE

Sampling Location Elimination Status		
Interpretation	SF → 0 (Perfect estimation)	SF → 1 (High estimation error)
CR or AR far from 1 (significant information loss)	Keep	Keep
CR → 1 and AR → 1 (less information loss)	Eliminate	Keep

FIGURE A.2.4 DECISION PROCESS OF ELIMINATION OF A LOCATION

Two kinds of thresholds are defined to judge whether or not to 1) eliminate a location or 2) to terminate the optimization. The SF threshold is defined for the first purpose. For example, if the SF threshold for all nodes is 0.40, those nodes with SF values less than 0.4 are potential nodes to be eliminated. CR and AR thresholds are defined for the second purpose. For example, if CR threshold is 0.85, elimination of locations is valid if the CR value is greater than 0.85. In this case, the acceptable level of information loss is 1 - 0.85 = 0.15, that is, 15%. If CR value is less than 0.85, the optimization should be terminated and the locations eliminated at this step should be re-instated. Details about these thresholds will be discussed shortly.

The Delaunay method performs the redundancy reduction by using an algorithm that considers all or a series of sampling events, of which optimization based on a single sampling event is a special case. Since each sampling event represents only one snapshot of the contaminant plume,

we need to examine all sampling events (or parts of them) to reveal the general spatial pattern of the contaminant distribution in a specific site. This general spatial pattern is the underlying assumption for the spatial analysis. In the Delaunay method, we find the general pattern by averaging across sampling events. In addition, since the spatial patterns of COCs may be different from each other, the optimization is performed based on each COC. Therefore, results are given separately in terms of each COC. Finally, we provide the all-in-one results simply by considering the most conservative result from all COCs. The major steps of this algorithm are as follows:

1) Select a series of continuous sampling events for analysis. They could be all sampling events in the monitoring history. They could also be any segment of sampling events in the monitoring history, e.g., sampling events in the past five years.
2) Calculate SF values of potential locations for all sampling events selected by the users, and for each COC.
3) Average SF values of potential locations across the selected sampling events for each COC, weighted by the number of locations contained in each sampling event. The results are lumped SF values of potential locations for each COC.
4) Eliminate one location at a step (*Single Step Optimization*) from each COC starting from the location with smallest lumped SF value. Calculate CR and AR ratios for each sampling event and then average them across sampling events to provide sampling-events-averaged CR and AR values. Compare sampling-events-averaged CR or AR values to thresholds and if there is no significant information loss, repeat this step with the next available location.
5) Provide the COC-categorized results after eliminating all redundant locations from each COC. In this step, elimination of a location in a COC means to stop sampling for that COC at that well in the next round of sampling.
6) Provide the all-in-one results by eliminating only those locations that are eliminated from all COCs. Here elimination of a location is equivalent to abandoning it, i.e., to stop service of a well since no COC needs to be sampled at this well any more.

The user can also choose to analyze only one sampling event, e.g., the latest sampling event. In this case, the step of averaging across sampling events is skipped, and more locations can be eliminated at a step. FIGURE A.2.5 shows the detailed procedures of optimization in this simplified process.

In MAROS, two modules are developed based on the Delaunay Method. One is the *Access Module* starting with screen *Sampling Location: Delaunay Method*, which is introduced in section **MAROS DETAILED SCREEN DESCRIPTIONS**. The other one is the *Excel Module - xlsDelaunay*, which is a stand alone Microsoft Excel Worksheet, discussed in section **MAROS DETAILED SCREEN DESCRIPTIONS**. The *Access Module* is designed to deal with multi-sampling-events analyses recognizing that a general spatial pattern may lie beneath what are revealed by each single sampling event. It can also be used to analyze a single sampling event, a special case of the multi-sampling-events analyses. The *Excel Module* is designed for one-sampling-event analyses, which provides the user with graphical interface and convenient controls to the optimization process, making the process of Delaunay Method better understood.

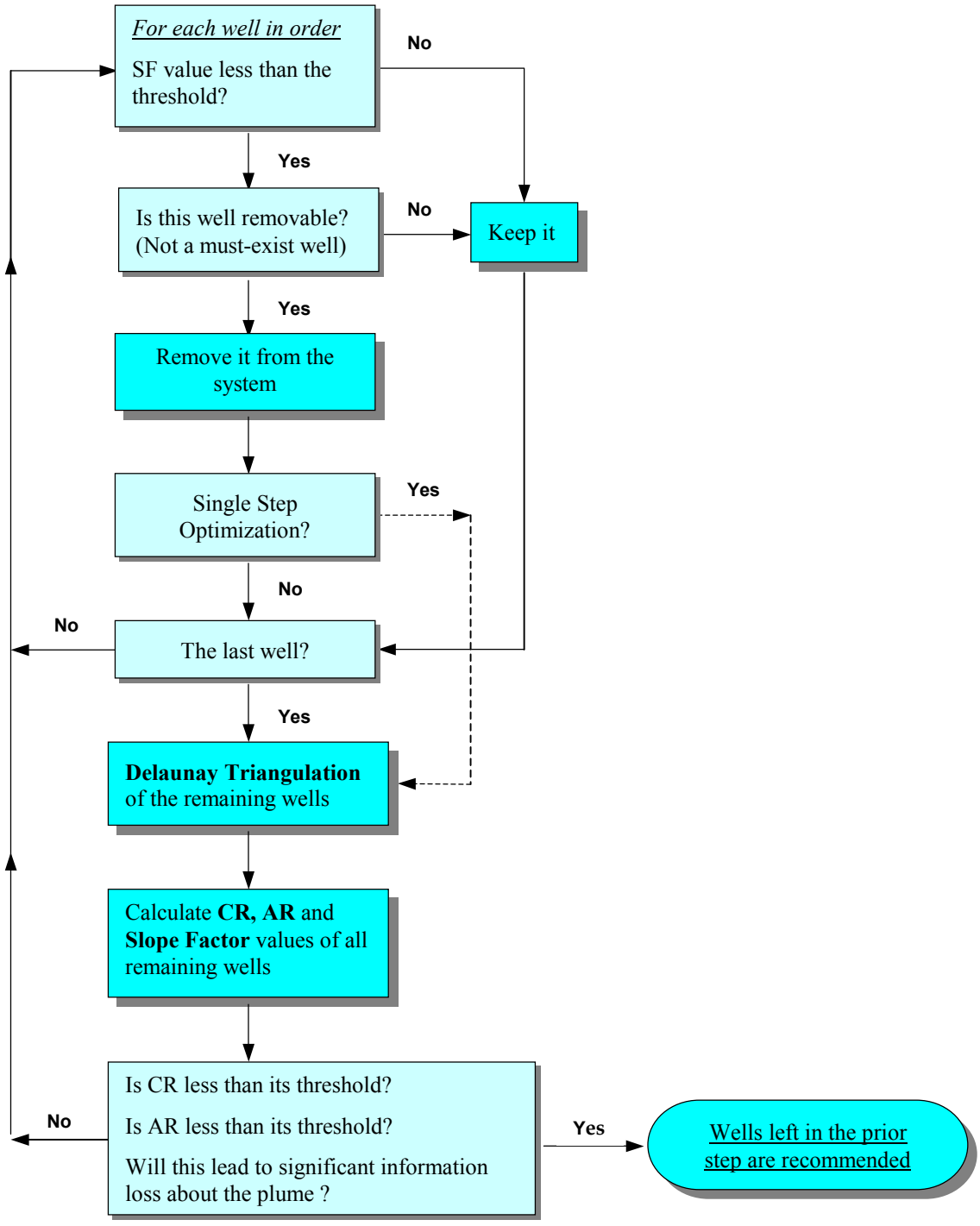


FIGURE A.2.5 STEPS OF OPTIMIZATION FOR ONE SAMPLING EVENT

Optimization Parameters

Inside node Slope Factor: The SF threshold for nodes (locations) located inside the triangulation domain. When SF of an inside node is less than this threshold, and if the node is *Removable*, it will be eliminated from the monitoring network. The current default value for this parameter is 0.4. *Removable* stands for the elimination property of a location. If the *Removable* property of a location is False, optimization can not eliminate it no matter how small its SF value is. This is important if you want to keep a location (e.g., a POC well) in the monitoring network. The default values for all potential locations are True.

Hull node Slope Factor: The SF threshold for nodes (locations) located on the edge (convex hull) of the triangulation domain. When SF of a hull node is less than this threshold, and if the node is *Removable*, it will be eliminated from the monitoring network. The current default value for this parameter is 0.1. The threshold for hull node is usually more stringent than that of the inside node, because the elimination of a hull node may cause reduction in the triangulation area, thereby causing greater information loss (reduction in AR). For contrast, the elimination of an inside node will only affect the average concentration ratio (CR).

Area Ratio (AR): The ratio of triangulation area (represents the area of a contaminant plume) at current optimization step to the original triangulation area before optimization. If the AR value in an optimization step is less than the threshold, the optimization will be stopped and locations eliminated in this step will be resumed. The default value is 0.85.

Concentration Ratio (CR): The ratio of average concentration of a contaminant plume at current optimization step to that of the original value before optimization. If the CR value in an optimization step is less than the threshold, the optimization will be stopped and locations eliminated in this step will be resumed. The default value is 0.90.

Single Step Optimization: The status of running optimization in single step, i.e., eliminates only one location at one optimization step. The *Access Module* uses only *Single Step Optimization*. The normal procedure is to eliminate all eligible nodes in one optimization step. The default value is FALSE for the *Excel Module*.

For the setting of these parameters, the user is referred to the corresponding parts in section **MAROS DETAILED SCREEN DESCRIPTIONS**.

Other Considerations

One thing to be bare in mind is that if the coordinates of a sampling location are not available, this location will be excluded and will not be shown in the analysis. The potential locations for analysis are only those with coordinates from the raw set of locations in the raw database (ERPIMS or others). The minimum number of wells valid for analysis is 6. If there are less than 6 wells, the Delaunay method won't work and give no recommendation.

References

Mace, R. E. et al., 1997, Extent, Mass, and Duration of Hydrocarbon Plumes from Leaking Petroleum Storage Tank Sites in Texas, University of Texas at Austin and TNRCC.

Okabe, A., Boots, B., and Sugihara, K., 1992, *Spatial Tessellations: Concepts and Applications of Voronoi Diagrams*, Wiley & Sons, New York.

Rice, D. W. et al., 1995, California Leaking Underground Fuel Tank (LUFT) Historical Analyses, UCRL-AR-122207, California State Water Resources Control Board.

Watson, D., 1994, N*ngridr – An Implementation of Natural Neighbor Interpolation*, D. F. Watson, Claremont, WA, Australia.

APPENDIX A.3 — MODIFIED CES METHOD

Authors: Ling, M. and Rifai, H. S., University of Houston.

In MAROS, the Modified CES method is used to determine the sampling frequencies at all sampling locations for each COC. The Modified CES method is developed based on the Cost Effective Sampling (CES, Ridley et. al. 1995) from Lawrence Livermore National Laboratory (LLNL). The Modified CES method is designed to reduce the sampling frequency based on the analysis of time series sampling data in each sampling location, considering both recent trends and long term trends of the concentration data. In contrast to the Delaunay Method that is based on the spatial analysis, the Modified CES method is an approach based on temporal analysis. Its combined use with the Delaunay Method leads to a complete process of sampling optimization.

Cost Effective Sampling

Cost Effective Sampling (CES) is a methodology for estimating the lowest-frequency sampling schedule for a given groundwater monitoring location while it can still provide the needed information for regulatory and remedial decision-making.

Its initial development at LLNL was motivated by the preponderance of sampling results which fall below detection limits at two of its restoration sites. The fact that so many locations had never shown, or had ceased for some time to show, any detectable levels of contamination suggested that those groundwater monitoring wells were being sampled more often than necessary.

The CES method recommends three steps for determining the sampling frequencies.

Step 1. Set frequency based on recent trends. Based on the trends determined by rates of change from linear regression analysis, a location is routed along one of four paths. The lowest rate, 0-10 ppb per year, leads to an annual frequency schedule. The highest rate, 30+ ppb per year, leads to a quarterly schedule. Rates of change in between these two extremes are qualified by variability information, with higher variability leading to a higher sampling frequency. Variability is characterized by a distribution-free version of the coefficient of variation: the range divided by the median concentration with 1.0 as the cut-off.

Step 2. Adjust frequency based on overall trends. If the long-term history of change is significantly greater than the recent trend, the frequency may be reduced by one level. If this is not so, no change could be made.

Step 3. Reduce frequency based on risk. Since not all compounds in the target list are equally harmful, frequency is reduced by one level if recent maximum concentration for compound of high risk is less than one half of the MCL.

It was stated that the evaluation by CES should be performed at the end of each year's monitoring. All the target chemicals should be evaluated to finally make the decision. Latest updates by LLNL include biennial sampling of the well if three successive annual recommendations are made, and the cut-off value of variability at high concentrations.

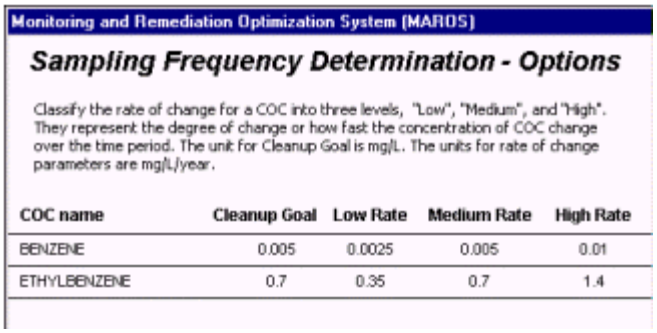
The adoption of minimum frequency of "quarterly" sampling is referred to Barcelona et. al (1989). The use of sampling intervals at Quarterly, Semi-Annual, Annual and Biennial is very common in long-term groundwater monitoring (AFCEE 1997, NFESC 2000) and is adopted in MAROS.

Details of Modified CES Method

Based on the CES method, we made some modifications to it and developed the so-called Modified CES method. The Modified CES method has three major steps that are similar to those of the CES method. The details of the decision procedures for the three major steps are given in the sub-sections starting from the next page.

In the Modified CES method, Concentration Trend (**CT**) by GSI (Groundwater Services, Inc.) style Mann-Kendall analysis is used instead of the distribution-free version of the coefficient of variation for the characterization of the variability. The GSI style Mann-Kendall trend results fall into 6 categories: Decreasing (**Decr**), Probably Decreasing (**ProbDecr**), **Stable**, **No Trend**, Probably Increasing (**ProbIncr**), and Increasing (**Incr**). The result of nonparametric Mann-Kendall analysis is judged with Coefficient of Variation (standard deviation divided by sample mean) and Confidence in Trend to determine the trend category. For the details of this statistic, refer to the corresponding part in Appendix A.1.

The Rate of Change (ROC) parameters used for determining the linear trends of COC were generalized to include all possible ranges. The ROC parameters fall into five categories: Low (**L**), Low-Medium (**LM**), Medium (**M**), Medium-High (**MH**), and High (**H**). The ROC is simply the slope of the fitted line by linear regression. The user is required to define three ROC parameters, the Low rate, Medium rate, and High rate. The other two rates, Low-Medium and Medium-High will be automatically determined. The term *Cleanup Goal* or *PRG* (Primary Remediation Goal) is used in MAROS to stand for MCL. By default, the Low rate is defined as 0.5*PRG*/year, the Medium rate is defined as 1.0*PRG*/year and the High rate is defined as 2.0*PRG*/year, for all COCs. The Low-Medium rate is defined as the half way between the Low rate and the Medium rate, as is the same for Medium-High rate. The user should provide more accurate values for these ROC values, if accurate classification is available from the hydrogeologic setting in the studied site. The unit of the ROC parameters is mg/L/year.

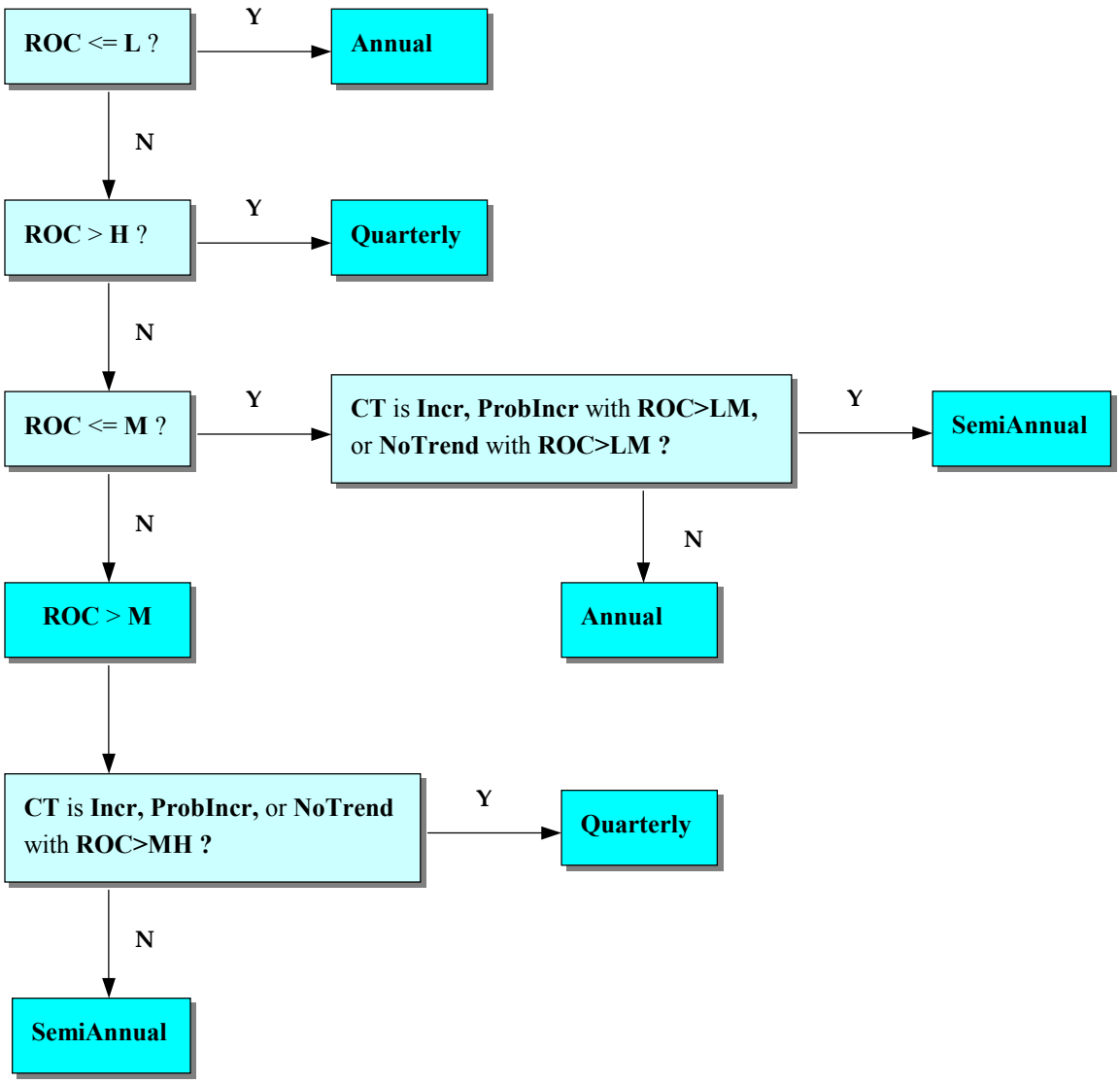


For example, in the right screen, the Cleanup Goal for Benzene is 0.005 mg/L. Then the default Low rate is 0.5 × 0.005 = 0.0025 mg/L/year, unless the user provides a site-specific value. According to the definition, the default Medium rate is 0.005 mg/L/year, and the default Low-Medium rate is (L+M)/2 = (0.0025+0.005)/2 = 0.00375, etc. For details on how to set these parameters, refer to the corresponding parts in section **MAROS DETAILED SCREEN DESCRIPTIONS**.

In MAROS, the determination of sampling frequencies by using the Modified CES method starts with screen *Sampling Frequency Determination*, which is introduced in section **MAROS DETAILED SCREEN DESCRIPTIONS**.

1) DETERMINE FREQUENCY BY RECENT TRENDS

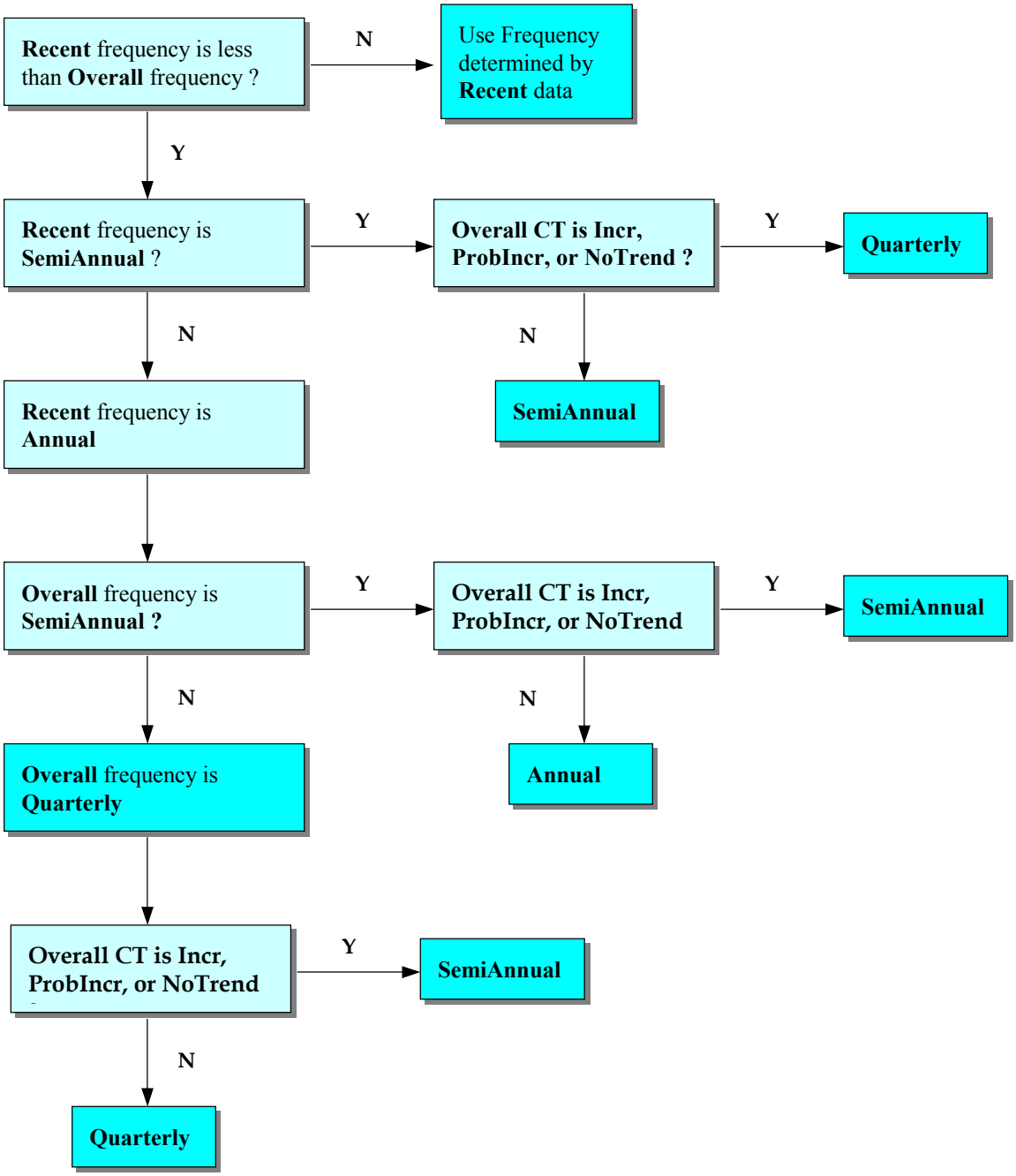
Frequency can be determined by results from both recent trends and overall trends. In this step, we need to determine the frequency based on recent trends using the procedures shown below.



Then similar procedures are used to determine the sampling frequency based on overall trends. In this step, the determined sampling frequency can be one of three possible results: Annual, Semi-Annual, or Quarterly. The adjustment based on recent/overall ratio will be performed in the next step. FIGURE A.3.1 gives a quick decision matrix that is similar in function to the above flowchart but is more illustrative of the results.

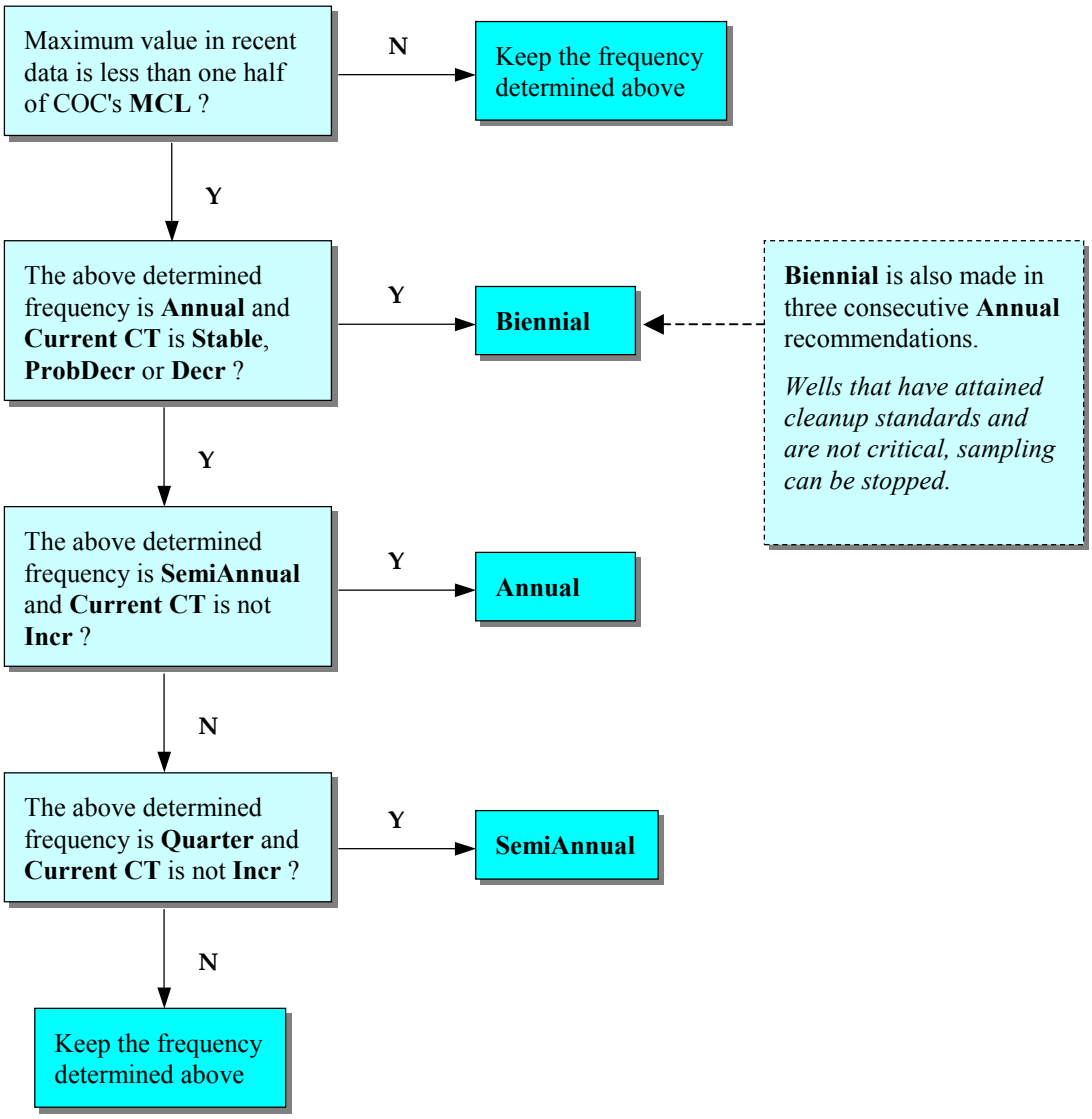
2) ADJUSTMENT BASED ON RECENT/OVERALL RATIO

If the frequency determined from overall trend is greater than that from the recent trend, e.g., the overall frequency is Quarterly while the current frequency is Annual, we might need to adjust the recent frequency by one level. When the recent trend is significantly lower than the long-term trend, reducing the sampling frequency gradually will ensure safety. The steps to be followed are shown in the following flow chart.



3) ADJUSTMENT BASED ON MCL

If the maximum concentration in the sample is less than one half of the MCL, and if the trend of COC in this well is not increasing, we can reduce the sampling frequency by one level. Because at such a low concentration level and with confidence that it will not increase, the adjustment will not cause great risk. The steps to be followed are shown in the following flow chart. In addition, wells that have attained cleanup standards (their long-term concentrations were far less than MCL) can be eliminated from the monitoring network to further optimize the monitoring program. Some of the empirical rules are referred to NFESC (2000).



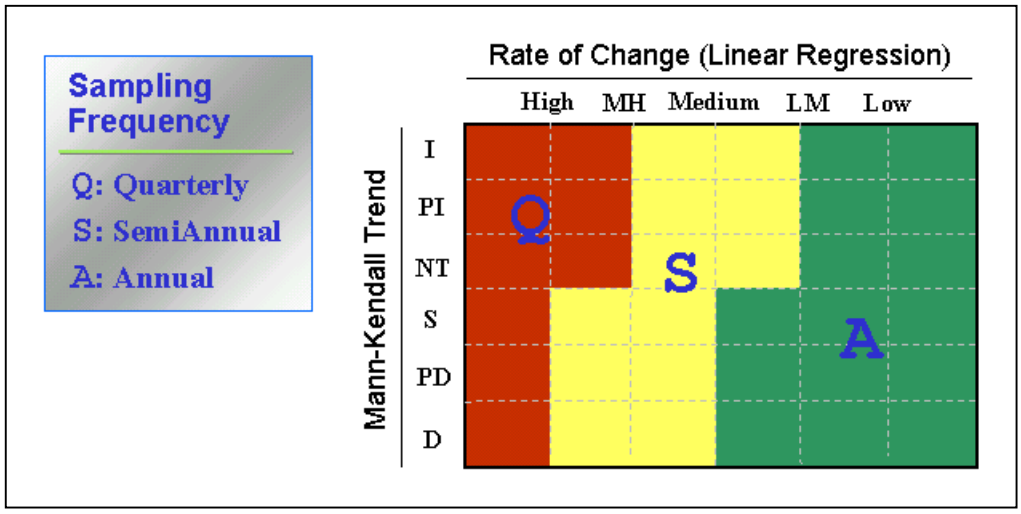
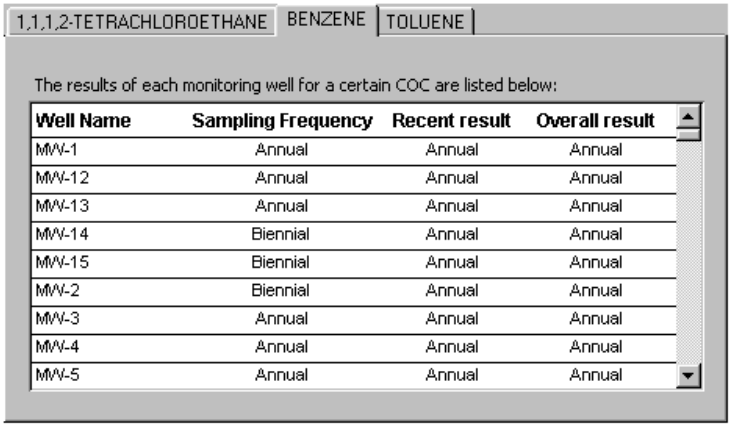


FIGURE A.3.1 DECISION MATRIX FOR DETERMINING FREQUENCY.

As is shown in the above three major steps, the Modified CES method is concerned not only with the magnitude of ROC, but also with the direction of change. The GSI style Mann-Kendall analysis is adopted because it can perform distribution-free test and provides us the direction of change. Usually people are more concerned with increasing trend than decreasing trend, assuming they have the same ROC. Regulator tends to impose more stringent sampling plan if the trend is increasing. An increasing trend can cause the concentration exceeding MCL and make a well non-compliant. On the contrast, a decreasing trend may drop the concentration below MCL and turn the well into compliance. All these examples indicate that attention must be paid to the direction of trend as well as the magnitude of trend. As discussed above, the modified CES method incorporated these considerations into the whole process of decision.

The final results include the recent result (based on the analysis of recent data), overall result (based on the analysis of overall data) and the final recommendation after two steps of adjustments. As is shown in the right screen, the *Sampling Frequency* for MW-15 is Biennial. Both the *Current* and *Overall* results for MW-15 are Annual. Its recommended frequency can be used in the future round of sampling.



Well Name	Sampling Frequency	Recent result	Overall result
MW-1	Annual	Annual	Annual
MW-12	Annual	Annual	Annual
MW-13	Annual	Annual	Annual
MW-14	Biennial	Annual	Annual
MW-15	Biennial	Annual	Annual
MW-2	Biennial	Annual	Annual
MW-3	Annual	Annual	Annual
MW-4	Annual	Annual	Annual
MW-5	Annual	Annual	Annual

Both parts of the sampling optimization — sampling location determination (based on the Delaunay Method) and sampling frequency determination (based on Modified CES method) should be performed periodically to ensure regular optimization of the groundwater monitoring program.

References

AFCEE, 1997, Long-Term Monitoring Optimization Guide - Version 1.1, HQ Air Force Center for Environmental Excellence, Consultant Operations Division, Brooks Air Force Base, TX.

Barcelona, M. J. et al., 1989, Sampling Frequency for Ground-water Quality Monitoring, EPA/600/S4-89/032, Environmental Monitoring Systems Laboratory, U.S. EPA.

NFESC, 2000, Guide to Optimal Groundwater Monitoring - Interim Final, Naval Facilities Engineering Service Center, Port Hueneme, California.

Ridley, M. N. et al., 1995, Cost-Effective Sampling of Groundwater Monitoring Wells, the Regents of UC/LLNL, Lawrence Livermore National Laboratory.

APPENDIX A.4 SECONDARY LINE OF EVIDENCE: EMPIRICAL DATA

Authors: Newell, C.J. and Aziz, J. J., Groundwater Services, Inc.

Objective

There is a growing body of empirical knowledge about the general behavior of groundwater plumes that in **some cases** might be a **useful secondary line of evidence** for evaluating plume behavior. Webster's New Riverside Dictionary defines "*empirical*" as

> "Relying on or gained from observation or experiment rather than theory"

The idea behind using empirical data as a line of evidence is summarized by one of the conclusions from an extensive chlorinated solvent plume study performed by the Lawrence Livermore National Laboratory:

> "Statistical methods, such as general linear models and comparison of probability distributions of plume length indices are useful to quantify expected relationships between plume length and site and CVOC variables within a population of CVOC plumes. In addition, they provide population statistics that may be used to bound the uncertainty inherent in expected plume behaviors." McNab et al, 1999

The empirical data for groundwater plumes has been derived from a series of multiple-site statistical studies sometimes called "plume-a-thon" studies. These include: plume-a-thon studies of:

- BTEX plumes in California, Texas, Florida, and nationwide (four studies);
- MTBE plumes in California and Texas (two studies);
- Chlorinated solvent plumes nationwide (two studies)

In the MAROS system, the user has the **option**, but not the requirement, to use the body of empirical data on plume behavior to help design and optimize a monitoring system.

Key Points/Caveats

Key points regarding the use empirical data as a secondary line of evidence are summarized below:

- Use of empirical data as a line of evidence is optional to the user;
- The empirical data, if used, should be considered secondary evidence and not weighted as much as the primary evidence
- The application of the empirical data is subjective and controlled by the user; i.e., MAROS does not take data, compare to the empirical data, and make a conclusion.
- To use empirical data as a secondary line of evidence, the user

i) reviews the empirical data in this appendix;

ii) based on the user's judgement assigns a plume stability class for each COC (i.e., designates each COC plume in the source and tail as Increasing, Probably Increasing, No Trend, Stable, Probably Decreasing, or Decreasing;

iii) assigns a weighting where the importance of the empirical data (a secondary line of evidence) is compared to the importance of the other three lines of evidence (i.e., Mann-Kendall analysis, a primary line of evidence; Linear Regression, a primary line of evidence; and modeling results, a secondary line of evidence). (see "LTM Analysis" section for a discussion of weighting the different lines of evidence).

(Note that the default weighting system in the software is to weight the two primary lines of evidence with a "medium" weight, while the two secondary lines of evidence (including empirical rules) is weighted "low". Again, if the users does not want to use empirical rules as a secondary line of evidence then the user can select that option in the software, or select "Don't Use" in the weighting selection.)

Using Empirical Data as Secondary Evidence

APPROACH

Step 1. Determine if you have a plume in one of the following general categories:

a) BTEX Plumes, Small Releases: BTEX plume from a small fuel release (such as a gas station release) (SEE PAGE A.4-4)

b) BTEX Plumes, Larger Releases: BTEX plume from a larger fuel release (such as from a tank farm) (SEE PAGE A.4-8)

c) MTBE plumes from a small fuel release (such as a gas station release) (SEE PAGE A.4-9)

d) Chlorinated solvent plumes (SEE PAGE A.4-12)

Step 2. Compare the length of you plume to the statistical characteristics of the other plumes from its class by going to the appropriate section (A. B. C. or D. below)

Step 3. If your plume is **much shorter** than most of the other plumes in its class, there may be secondary evidence that your plume has a higher potential to expand. You should select "Increasing" or "Probably Increasing" and enter in software. (Of course if you feel the evidence is not strong enough to be significant, you have the option to not use empirical rules as a line of evidence.)

If your plume is **much longer** than most of the other plumes in its class, there may be secondary evidence that your plume has a lower potential to expand. You should select "Decreasing" or "Probably Decreasing" and enter in software. (Of course if you feel the evidence is not strong enough to be significant, you have the option to not use empirical rules as a line of evidence.)

If your plume is **about the same length** than most of the other plumes in its class, may be weak secondary evidence that your plume may neither increase or decrease in length. You should select "Stable" or "No Trend" and enter in software. (Of course if you feel the evidence is not strong enough to be significant, you have the option to not use empirical rules as a line of evidence.)

Step 4. If available, review the data about plume stability for your particular plume class of interest. For example, plume-a-thon studies of fuel plumes in California (Rice et al, 1995) and Texas (Mace et al., 1997) indicate that most BTEX plumes from small gasoline station releases are either stable, shrinking, or exhausted. If your plume is a BTEX plume from a small release such as a gas station, there may be additional secondary evidence that your plume is more likely "Stable" or "Probably Decreasing" or "Decreasing" as opposed to "Increasing." It is important that the user's experience about the site is used when applying the empirical rules.

For example, a very recent release has a much higher potential for expanding than most of the plumes in the plume-a-thon databases. In summary, the empirical data are designed to be supporting, secondary lines of evidence that are used carefully based on the user' s experience and site knowledge.

A. Empirical Data, BTEX Plumes – Small Releases

Recent studies of over 600 groundwater contamination sites throughout the U.S. provide important information regarding the fate and transport of petroleum hydrocarbons in the subsurface. An API research summary (Newell and Connor, 1998) examined the findings of four independent research studies and addressed several key technical issues regarding the assessment and remediation of BTEX (benzene, toluene, ethylbenzene, xylene) plumes. Each study involved detailed analysis of data from a large number of sites (primarily leaking underground storage tanks) to identify the salient characteristics of groundwater contaminant plumes caused by petroleum hydrocarbon releases. Two studies (California and Texas) evaluated the trends in dissolved petroleum hydrocarbon plumes.

PLUME LENGTH DATA (USED FOR STEP 3)

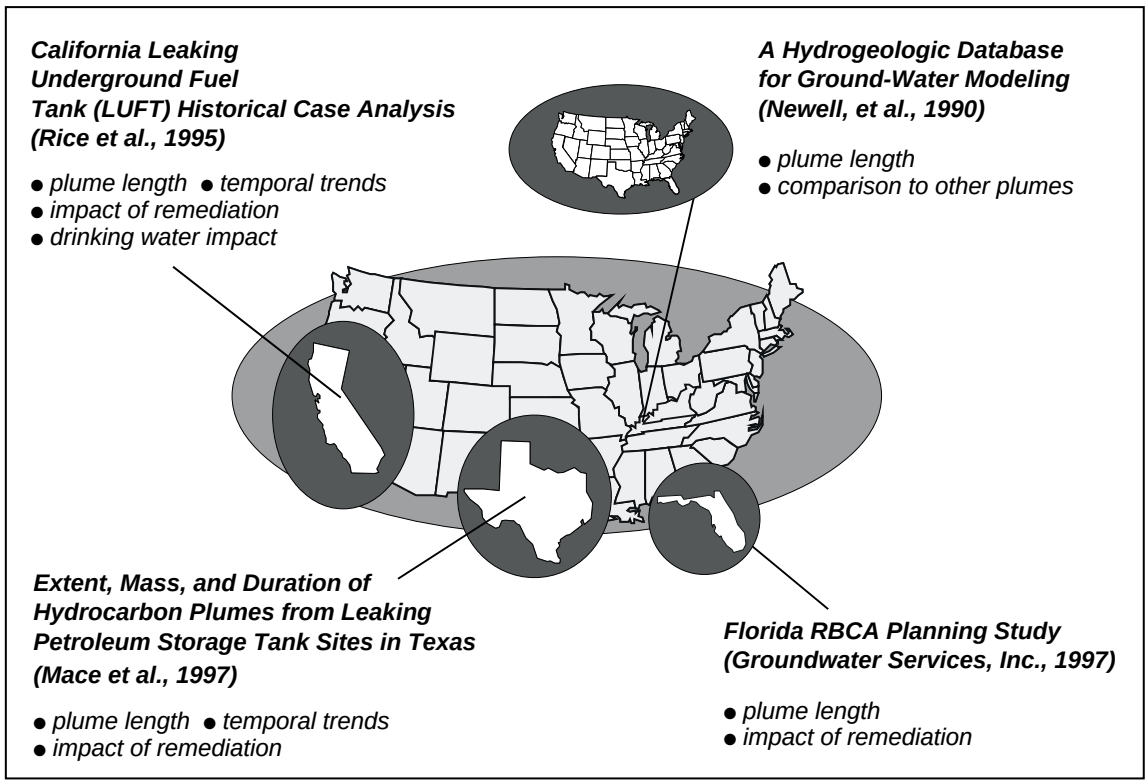


FIGURE A.4.1. LOCATION OF "BTEX PLUMES, SMALL RELEASE" STUDIES

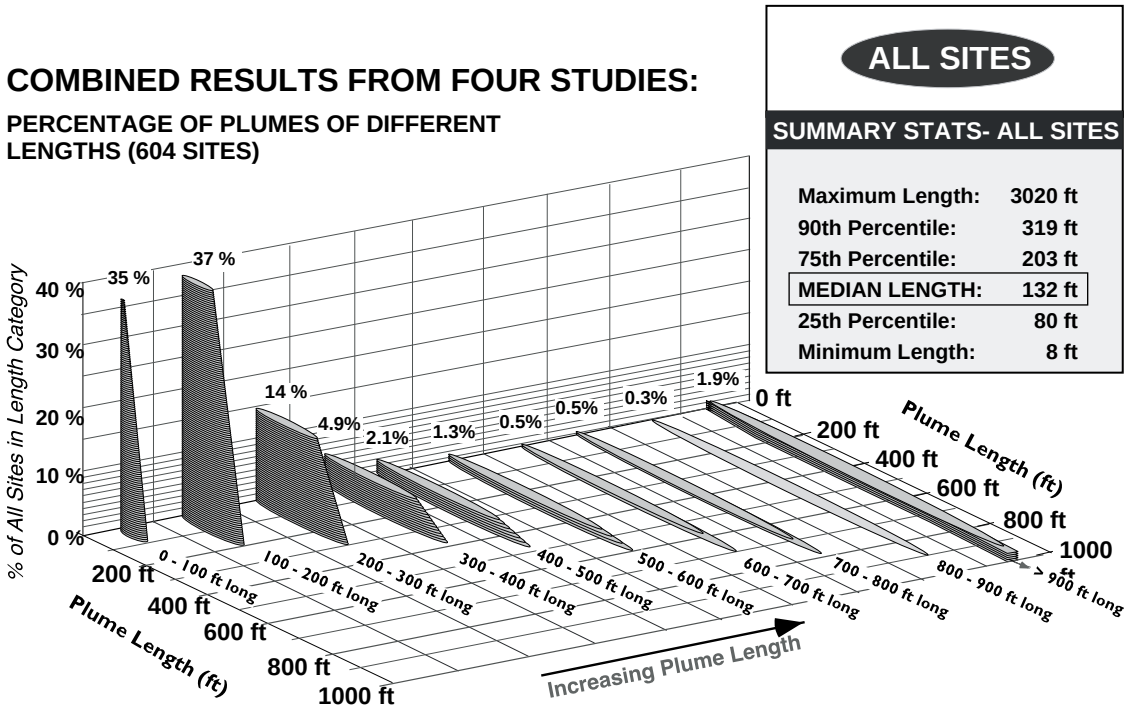


FIGURE A.4.2. LIMIT OF MIGRATION OF PETROLEUM HYDROCARBON PLUMES, BASED ON COMBINED RESULTS FROM FOUR STUDIES (NEWELL AND CONNOR, 1998). FOUR STUDIES INCLUDED THE LAWRENCE LIVERMORE STUDY (RICE ET AL. 1996), TEXAS BEG STUDY (MACE ET AL., 1997), FLORIDA RBCA STUDY (GSI, 1997), AND UNPUBLISHED DATA FROM THE HGDB DATABASE (NEWELL ET AL., 1990).

CALIFORNIA	TEXAS	FLORIDA	HGDB
271 Sites	217 Sites	74 Sites	42 Sites
Summary Stats	**Summary Stats**	**Summary Stats**	**Summary Stats**
Max 1713 ft	Max 1619 ft	Max 600 ft	Max 3020 ft
90th % 255 ft	90th % 382 ft	90th % 211 ft	90th % 945 ft
75 % 146 ft	75 % 250 ft	75 % 158 ft	75 % 400 ft
MEDIAN 101 ft	**MEDIAN 181 ft**	**MEDIAN 90 ft**	**MEDIAN 213 ft**
25th % 66 ft	25th % 137 ft	25th % 60 ft	25th % 85 ft
Min 8 ft	Min 54 ft	Min 12 ft	Min 15 ft

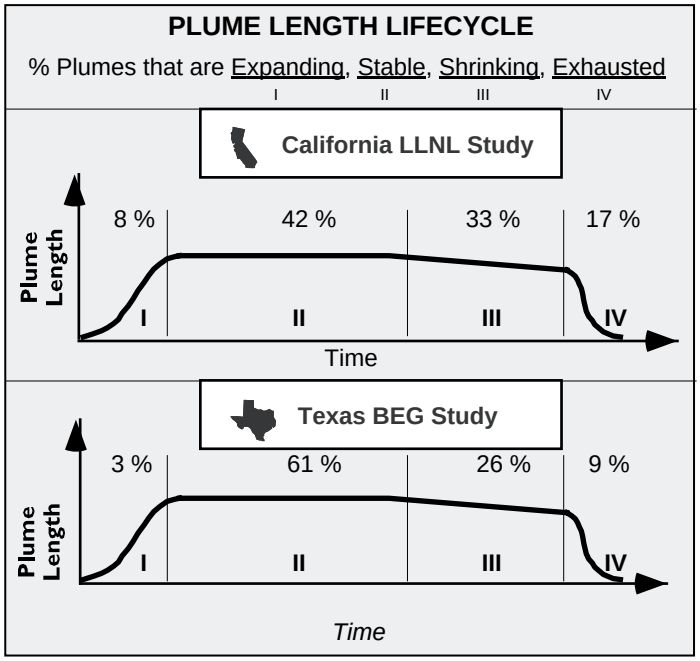
FIGURE A.4.3. SUMMARY STATISTICS FOR INDIVIDUAL PLUME-A-THON STUDIES. MOST STUDIES FOCUSED ON BENZENE OR BTEX RELEASES FROM SMALL FUEL RELEASES SUCH AS UNDERGROUND STORAGE TANKS (USTS) AT SERVICE STATIONS.

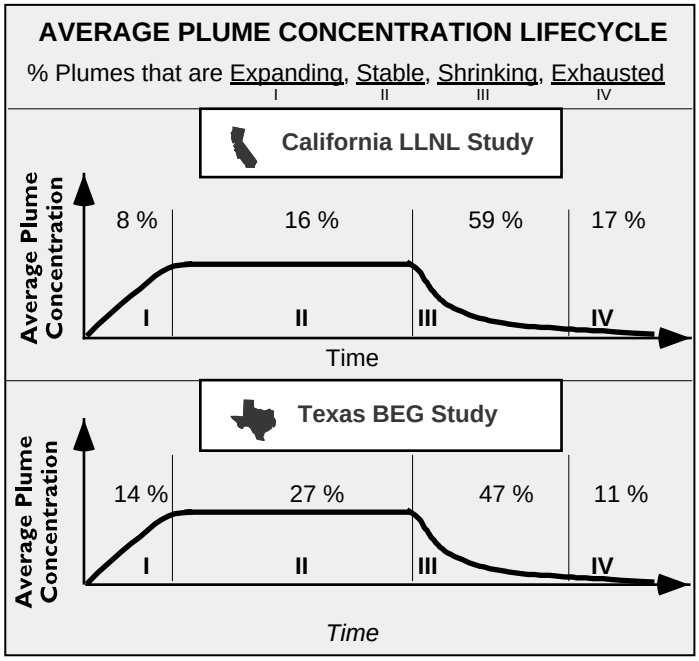
PLUME TREND DATA (USED FOR STEP 4)

Two studies (California and Texas) evaluated the trends in dissolved petroleum hydrocarbon plumes. Rice et al, (1995) developed the following classification system to evaluate BTEX plume trends:

- Expanding: Residual source present. Mass flux of contaminants exceeds assimilative capacity of aquifer.
- Stable: Insignificant changes. Active or passive remediation processes are controlling plume length.
- Shrinking: Residual source nearly exhausted, and active or passive remediation processes significantly reducing plume mass.
- Exhausted: Average plume concentration very low (e.g., 1 ppb) and unchanging over time. Final stages of source zone dissolution over a relatively small area at a site.

As shown in the conceptual plume lifecycle figure below (see Figure A.4.4), of the nearly 500 sites addressed by this analysis, nearly 75% were found to be in either a stable or shrinking condition, based on analyses of both plume length and concentration. Plume concentrations were predominantly shrinking (47 to 59%), whereas lengths were frequently stable (42 to 61%). These results suggest that dissolved hydrocarbon plumes tend to reduce more rapidly in concentration than in length.





Figures adapted from Rice et al., 1996.

FIGURE A.4.4 TEMPORAL TRENDS FOR PLUME LENGTH (TOP) AND AVERAGE PLUME CONCENTRATION (BOTTOM) FOR BTEX PLUMES, SMALL RELEASES.

B. Empirical Data, BTEX Plumes – Larger Releases

PLUME LENGTH DATA (USED FOR STEP 3)

Data from other releases besides UST sites suggests that longer BTEX plumes are possible. One data set, derived from a plume data compiled by Wiedemeier et al. (1999) shows 18 Air Force plumes with a median BTEX plume length of 530 ft (see Table A.4.1).

TABLE A.4.1. LENGTH OF BTEX PLUMES FROM LARGER FUEL RELEASES (DATA FROM WIEDEMEIER ET AL., 1999)

BTEX SITES , LARGER RELEASES	State	Plume Length (ft)
Elmendorf AFB	AK	3000
Dover AFB	DE	3000
Hill AFB	UT	1650
Myrtle Beach - POL Facility	SC	1150
Battle Creek	MI	900
King Salmon AFB	AK	850
Madison ANGB	WI	750
Pope AFB- FPTA #4	NC	720
Elmendorf AFB	AK	700
Griffis AFB	NY	360
Columbus AFB	MS	350
MacDill AFB	FL	350
Seymour Johnson AFB	NC	315
Eglin AFB- POL Facility	FL	300
MacDill AFB	FL	250
Westover AFB- Fire Training	MA	200
Fairchild AFB	WA	175
Langley AFB	VA	140
Maximum		3000
90% Percentile		2055
75% Percentile		888
MEDIAN		530
25% Percentile		304
Minimum		140
Number of Sites		18

PLUME LENGTH CORRELATION EQUATIONS (USED FOR STEP 3)

A second approach to compare your plume against empirical plume data is using correlation equations. One takes site data from your site, applies the correlation equation, and then obtains a **predicted plume length**. Then one uses the approach outlined in Step 3 to estimate plume behavior.

For example, if your plume is **much shorter** than **predicted plume length**, then there may be secondary evidence that your plume has a higher potential to expand. You should select "Increasing" or "Probably Increasing" and enter in software. On the other hand, if your plume is **much longer** than the **predicted plume length**, there may be secondary evidence that your plume has a lower potential to expand. You should select "Decreasing" or "Probably Decreasing" and enter in software.

Correlation Equations for BTEX Plumes

Some correlation equations for BTEX plumes are provided in Wiedemeier et al. (1999; see page 229-230).

A more detailed correlation analysis was performed for the American Petroleum Study by Nevin et al. analyzed plume length data UST and petroleum release sites taken from the four sources (the HGDB Air Force plumes, the Texas BEG study, and Florida RBCA study). The database includes sites ranging from small retail gas stations to large distribution sites covering thousands of square feet. This wide range of site sizes makes the study database different from the databases used in the Lawrence Livermore (LLNL, see Rice, et al., 1995) and Texas BEG (see Mace, et al., 1997) studies, which were almost entirely retail sites.

Using this database, correlations were performed on a number of hydrogeologic and source parameters. The correlation results agreed with results from the California and Texas plume-a-thon studies (Rice et al., 19995; Mace et al, 1997) that showed that plume length is not correlated with groundwater velocity or other hydrogeologic characteristics of the site.

The correlation study also confirmed that the source size is a major determining factor for plume length. Because transverse dispersion is a relatively weak process (Pankow and Cherry, 1996), the plume width was used as an approximation for the source width. As shown below, there is high degree of correlation ($R^2 = 0.67$) was found between plume length and plume width. Although this may appear to be self-evident, it is a key conclusion in that it supports the idea that BTEX plume length is largely driven by source factors, and much less by hydrogeologic factors.

The resulting plume length prediction equation is:

$$\text{Plume Length (ft)} = 2.0 \bullet \text{Plume Width (ft)} \quad R^2 = 0.67$$

This results is supported by qualitative conclusions by the California and Texas plume-a-thon studies. Rice et. al (1995) concluded "These hypothetical plume-length controlling variables may be source mass and passive bioremediation rate." Mace et al. (1997) identified other factors, such as the amount of spilled fuel and natural biodegradation rate, as having a greater influence than hydrogeology or previous remediation activities.

C. Empirical Data, MTBE Plumes

Two plume-a-thon studies have been conducted on MTBE plumes, one if California and one in Texas.

MTBE PLUME LENGTH DATA (USED FOR STEP 3)

California Study

Happel et al., 1998) performed a study of 63 MTBE sites in California. They concluded that:

"MTBE plumes were typically equivalent in length, or shorter than benzene plumes. On a site-by-site basis, this was also true in approximately 81% of the cases. Further at an individual LUFT site, the length of a benzene plume was only moderately correlated with the length of the corresponding MTBE plume; thus the length of a benzene plume cannot be used to predict the extent of MTBE impact."

TABLE A.4.2 CUMULATIVE DISTRIBUTIONS OF 1995/96 PLUME LENGTHS (IN FT) FOR BENZENE AND MTBE (SOURCE: FIGURE 4.1, HAPPEL ET AL., 1998).

Maximum	1000 ft
90% Percentile	325
75% Percentile	250
MEDIAN	120
25% Percentile	85
Minimum	0
Number of Sites	50

The median MTBE plume length was approximately 120 ft.

Mace and Choi studies 99 MBTE plumes in Texas, and compiled the following distribution for MTBE plume lengths:

TABLE A.4.3 CUMULATIVE DISTRIBUTIONS OF 10 PPB MTBE PLUME LENGTHS (IN FT) FOR 99 SITES IN TEXAS (SOURCE: FIGURE 3, MACE AND CHOI, 1998).

Maximum	750 ft
90% Percentile	386
75% Percentile	255
MEDIAN	174
25% Percentile	120
Minimum	0
Number of Sites	99

Mace and Choi found that MTBE plumes were, on average, only slightly longer than their companion benzene plumes.

MTBE PLUME TREND DATA (USED FOR STEP 4)

Caution should be take before using MTBE plume distributions as secondary evidence, as Happel et al. (1998) concluded that most of the MTBE plumes are not stable compared to the contaminant (e.g., BTEX) plumes:

> "Although our results using 1995/96 data indicate that, at the majority of sites, individual MTBE plumes were nearly equivalent or shorter than their corresponding benzene plumes (defined by action levels of 20 and 1 μg L -1 respectively), our results predict that at a portion of these sites this relationship will change over time as the contaminant plumes gradually dissociate." (Happel et al., 1998)

The Texas study arrived at the opposite conclusion, however:

> "Analysis of temporal data (83 percent of wells have stable, decreasing, or nondetection of MTBE concentration; co-occurrence with benzene has remained the same for the past several years; and limited plume length data shows sites with stable plumes) suggests that MTBE plumes may be naturally attenuated at many sites in Texas." (Mace and Choi, 1998).

More research is needed before MTBE plume-a-thon data can be used as adequate secondary evidence for determining plume stability.

D. Empirical Data, Chlorinated Solvent Plumes

Two chlorinated solvent plume-a-thons are available for use as secondary evidence, one performed for the Air Force Center for Environmental Excellence Tech Transfer Division by Groundwater Services, Inc., and one performed by the Lawrence Livermore National Laboratory.

CHLORINATED SOLVENT PLUME LENGTH DATA (USED FOR STEP 3)

AFCEE Study

The AFCEE database (Aziz et al., in review), used data from site investigation, treatability, and natural attenuation reports to compile the database. Questionnaires were completed using mean hydrogeologic property values extracted from the site reports for the most contaminated unit. Plume lengths were determined using isopleths for each chlorinated ethene or chlorinated ethane constituent included in the site report. The project developed several correlations to plume length and estimated first order biodegradation rates for both parent compounds and daughter products using the BIOCHLOR model (Aziz et al., 1999)

When comparing the chlorinated ethenes (i.e., PCE, TCE, c-DCE, t-DCE, and vinyl chloride), TCE and the DCE isomers have the longest median plume lengths, all in the 1200 ft range, as shown in Table A.5.4. Vinyl chloride has the shortest median plume length of 860 ft, followed by PCE with a plume length of 970 ft.

TABLE A.4.4 CUMULATIVE DISTRIBUTIONS OF CHLORINATED SOLVENT PLUME LENGTHS (IN FT) AND ASSOCIATED COMPOUNDS PLUME LENGTHS (IN FT) (SOURCE: TABLE 3, AZIZ ET AL, IN REVIEW).

	Plume Lengths (ft)						
	Minimum	25th Percentile	Median	75th Percentile	Maximum	Mean	n
PCE	100	228	**970**	1335	13700	1933	11
TCE	250	450	**1215**	2600	11900	2137	21
cis-DCE	200	540	**1205**	3100	9400	2046	20
trans-DCE	440	1190	**1200**	1890	2750	1494	5
VC	180	398	**860**	1310	3300	1084	15
Ethene	120	320	**600**	1045	1500	675	11
Chloride	270	863	**1418**	2900	4520	1848	14
BTEX	60	595	**750**	1270	3600	1183	15
TCA	130	365	**865**	2183	2700	1230	6
1,1-DCA	1040	1370	**1650**	1925	2500	1675	8
1,1-DCE	1000	1245	**1470**	1643	1820	1438	6

Key results from this study are (Aziz et al., in review):

- At sites contaminated with chlorinated ethenes only, TCE or c-DCE was the most likely constituent to have the longest plumes at the site. TCE and c-DCE had median plume lengths of 1215 ft and 1205 ft, respectively.
- VC had the shortest median plume length of 860 ft. Because the daughter product plumes were coincident or almost coincident with the parent plumes, these results indicate that vinyl chloride is unlikely to be the longest plume at a site. This is an encouraging result given the relatively high associated carcinogenicity of vinyl chloride.

- The plume width in the source area (or source area width) was used to represent the size of the NAPL-affected source area. The product of the source area width and the maximum dissolved phase solvent concentration was strongly correlated with plume length. This finding indicates that source characteristics, including the extent of DNAPL migration, are the most important factors impacting the maximum dissolved chlorinated solvent plume length.
- Chlorinated ethene plume lengths were moderately correlated with seepage velocity and groundwater travel distance, indicating that advection is also an important factor impacting chlorinated solvent plumes. Therefore, the seepage velocity should be accurately determined to predict plume lengths.
- Environmental factors, such as temperature, pH, dissolved oxygen, and redox potential were not strongly correlated with chlorinated ethene plume length. However, there was a strong trend of increasing PCE plume length with increasing redox potential, once the PCE plume length was normalized to remove the effects of advection. These results suggest that source width and strength and seepage velocity are more important factors impacting overall plume length than environmental conditions that are conducive to reductive dechlorination.

Lawrence Livermore Study

McNab et al. (1999) collected and analyzed data from 65 sites representing a variety of hydrogeologic settings and release scenarios (e.g., large industrial facilities, dry cleaners, and landfills). Data collection involved a variety of federal and state agencies and included participation from the U.S. Department of Defense, the Department of Energy, and private industry. The distribution of chlorinated solvent plume lengths from their database is shown in Table A.4.5:

TABLE A.4.5. SUMMARY OF FREQUENCY DISTRIBUTIONS OF MAXIMUM CVOC PLUME LENGTHS (FT) TO THE 10 PPB-DEFINED PLUME PER SITE, BASED ON THE INDICATED CONCENTRATION CONTOUR DEFINITION.

90% Percentile	6030 ft
75% Percentile	3210
MEDIAN	1600
25% Percentile	790
10% Percentile	120
Number of Sites	99

Key results from this study were:

- Statistical methods, such as general linear models and comparison of probability distributions of plume length indices are useful to quantify expected relationships between plume length and site and CVOC variables within a population of CVOC plumes. In addition, they provide population statistics that may be used to bound the uncertainty inherent in expected plume behaviors.
- An important conclusion of this study is that the presence of a vinyl chloride plume indicates that reductive dehalogenation may be playing a role in reducing the extent of CVOC plumes at approximately one-third of the sites examined. In contrast, the presence

of a cis-1,2-DCE plume in the absence of a vinyl chloride plume appears to indicate reductive dehalogenation rates that are insufficient to effectively reduce the extent of CVOC plumes at a site. Little evidence was found in the data to suggest that plume lengths and plume growth rates are substantially affected by reductive dehalogenation in these circumstances.

- There are no statistically significant differences between CVOC species with regard to their log-transformed 10-ppb plume lengths, including likely transformation daughter products such as cis-1,2-DCE and vinyl chloride. Plume lengths are positively correlated with maximum historical CVOC concentrations and mean groundwater velocity at each site. Large daughter product plumes do not commonly extend a large distance downgradient of the parent product plumes.

PLUME LENGTH CORRELATION GRAPHS (USED FOR STEP 3)

AFCEE Study

Aziz et al, (2000) also evaluated correlations to chlorinated solvent plume lengths. In general, the best correlation to log plume length (in ft) was log (Plume Width x Maximum Concentrations) as shown in Figure A.4.5.

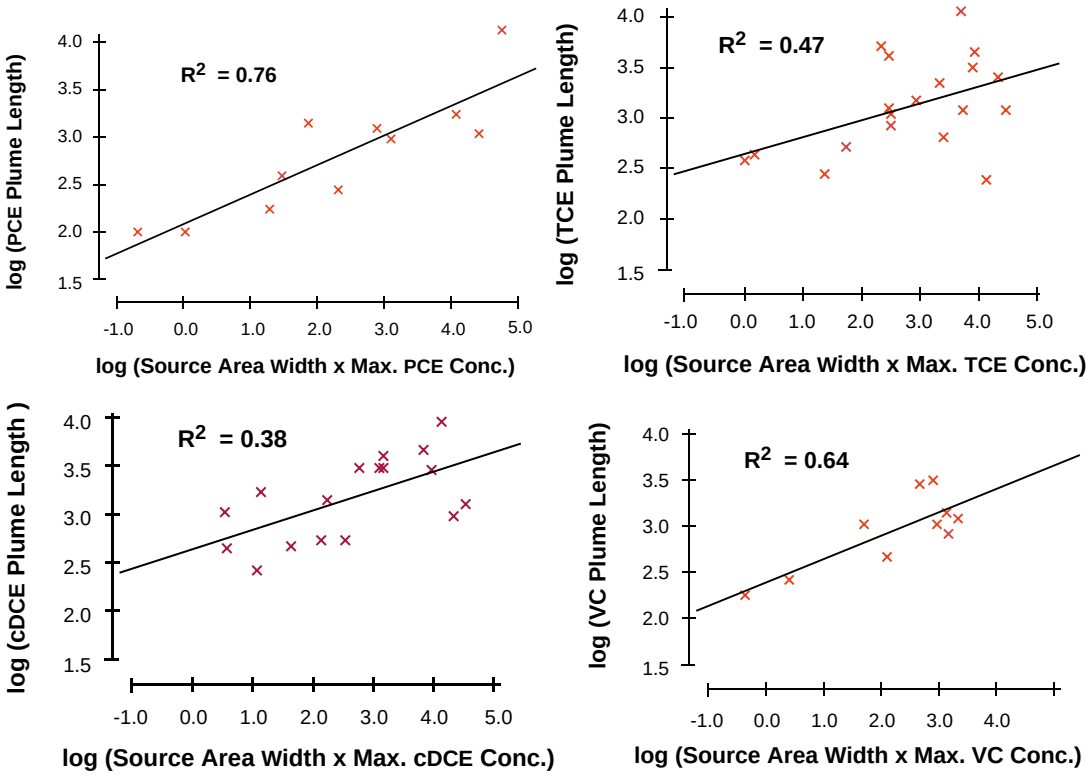


FIGURE A.4.5. CORRELATION OF LOG PLUME LENGTH WITH LOG (PLUME WIDTH X MAXIMUM CONCENTRATION) (AZIZ ET AL., 2000)

Lawrence Livermore Study

Numerous correlations were conducted as part of this chlorinated solvent plume study. The authors concluded that:

> Another important conclusion is that CVOC transformation rates through dehalogenation exert less impact on plume length than source strength and groundwater velocity. Thus, plumes with weaker source strength and slower groundwater velocities may be better candidates for the application of natural attenuation remedies.

CHLORINATED SOLVENT TREND DATA (USED FOR STEP 4)

Lawrence Livermore Study

As part of the Lawrence Livermore National Laboratory chlorinated solvent plume study (McNab et al, 1999), a time series analysis was performed. This analysis divided the chlorinated solvent plumes into two groups: a group with **Strong Reductive Dechlorination** processes (see Table A.4.6) and **No or Weak Reductive Dechlorination** processes (see Table A.4.7).

TABLE A.4.6. TEMPORAL TRENDS IN PLUME LENGTH FOR CVOC PLUMES FROM THE STRONG REDUCTIVE DECHLORINATION GROUP CHARACTERIZED BY MONITORING DATA FROM THREE OR MORE YEARS. SOURCE: MCNAB ET AL, 1999

p-value	Plumes Decreasing In Length		Plumes Increasing In Length		Plumes With No Significant Trend	
	% Sites	Number sites	% Sites	Number sites	% Sites	Number sites
0.01	9%	4	4%	2	87%	41
0.05	11%	5	13%	6	77%	36
0.1	13%	6	15%	7	72%	34
0.2	21%	10	19%	9	60%	28
0.3	21%	10	26%	12	53%	25
0.5	23%	11	28%	13	49%	23

TABLE A.4.7. TEMPORAL TRENDS IN PLUME LENGTH FOR CVOC PLUMES FROM THE NO REDUCTIVE DECHLORINATION AND WEAK REDUCTIVE DECHLORINATION GROUPS CHARACTERIZED BY MONITORING DATA FROM THREE OR MORE YEARS. SOURCE: MCNAB ET AL, 1999

p-value	Plumes Decreasing In Length		Plumes Increasing In Length		Plumes With No Significant Trend	
	% Sites	Number sites	% Sites	Number sites	% Sites	Number sites
0.01	9%	8	14%	13	78%	73
0.05	10%	9	21%	20	69%	65
0.1	12%	11	27%	25	62%	58
0.2	14%	13	34%	32	52%	49
0.3	17%	16	38%	36	45%	42
0.5	19%	18	44%	41	37%	35

The authors concluded that:

"Regardless of the confidence level, the two populations of plumes do appear to differ from one another according to this analysis in that the plumes from the Strong RD group exhibit a diminished tendency toward increases in plume length than those plumes from the No RD and Weak RD groups. Previous historical case analyses of fuel hydrocarbon plumes (Rice et al., 1995, Mace et al., 1997) indicated that only a small minority of hydrocarbon plumes (on the order of 10%) were experiencing discernable plume growth, presumably as a result of the limiting effects of biotransformation processes. Thus, the differences in apparent CVOC plume growth rates provides an independent line of evidence to support the conclusion that reductive dehalogenation influences plume length behavior at sites where vinyl chloride plumes are present."

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APPENDIX A.5 — MAROS SITE RESULTS

Authors: Newell, C.J. and Aziz, J. J., Groundwater Services, Inc.

The preliminary monitoring system optimization results are based on site classification, source treatment and monitoring system category (Figure A.5.1). The decision matrices below are heuristic rules based on the judgment of the authors. Users are expected to review and modify as necessary to reflect site specific hydrogeology, contaminants, risks and regulatory considerations. General recommendations by more rigorous statistical methods can be obtained by using the more detailed optimization approaches outlined in Appendices A.2 and A.3. General site results are outlined by for Sampling Frequency, Well Sample Density and Duration of Sampling. These criteria take into consideration: plume stability, type of plume, and groundwater velocity. The results are specific to only one COC. Each COC considered in the MAROS software is assigned a result based on the criteria outlined here.

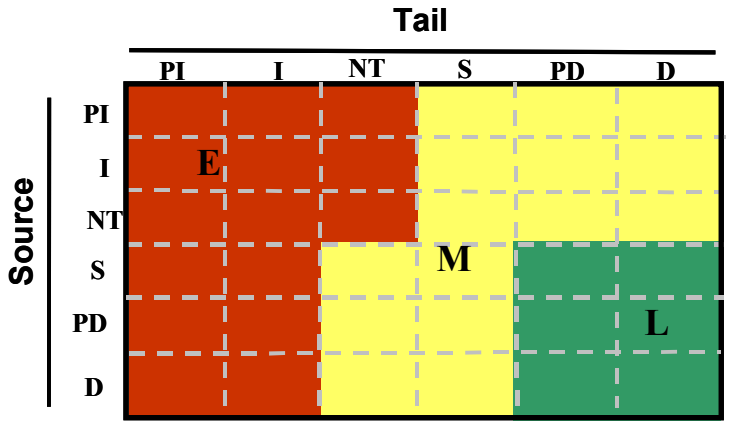

FIGURE A.5.1 DECISION MATRIX FOR ASSIGNING MONITORING SYSTEM CATEGORIES: MODERATE (M); EXTENSIVE (E); LIMITED (L); PLUME STABILITY: INCREASING (I); PROBABLY INCREASING (PI); NO TREND (NT); STABLE(S); PROBABLY DECREASING (PD); DECREASING(D).

Weighted Average

Two types of weighting are available within the MAROS Analysis software (i.e. LOE weighting and well weighting). The weighting for these analyses follow a simple weighted average defined as:

$$\text{Weighted Average} = \frac{\sum_{i=1}^{n} W_i X_i}{\sum_{i=1}^{n} W_i}, \text{ where } W_i \geq 0.$$

W_i is the weight of the value, X_i, in the MAROS software, high, medium, and low weight correspond to values 3, 2 and 1 respectively.

No Current Site Treatment

Sites not currently undergoing site treatment (i.e. no current site remediation method other than natural attenuation) have separate decision matrices applied (Tables A.5.1 to A.5.3)

FREQUENCY

MAROS uses a simple decision matrix to indicate how often wells at the site should be sampled to be sufficient for adequate groundwater monitoring. Users can compare the frequency of the sampling at their site to the suggested frequency of monitoring evaluated based on the decision matrix below. If their site has wells being sampled at a significantly higher interval, then some reduction in the sampling frequency could be applied. Note that user can apply the sampling optimization (Sample Frequency) wing of the software to perform a more rigorous analysis of the sampling frequency required for monitoring.

The sampling frequency at the site is determined by the Monitoring System Category assigned by the results from the Source and Tail Stability as well as the "Time to Receptor". Sites with both decreasing Source and Tail Results are recommended for closure.

TABLE A.5.1 FREQUENCY DETERMINATION FOR SITES WITH NO GROUNDWATER FLUCTUATIONS AND NO CURRENT SITE TREATMENT.

TTR	Monitoring System Category		
	E	M	L
Close (TTR < 2 yrs)	Quarterly	Biannually (6 months)	Annually
Medium (2 < TTR < 5 yrs)	Biannually (6 months)	Annually	Annually
Far (TTR > 5 yrs)	Annually	Annually	Biennially (2 year interval)
TTR: time to receptor (distance to receptor/seepage velocity)			

TABLE A.5.2 FREQUENCY DETERMINATION FOR SITES WITH GROUNDWATER FLUCTUATIONS AND NO CURRENT SITE TREATMENT.

TTR	Monitoring System Category		
	E	M	L
Close (TTR < 2 yrs)	Quarterly	Quarterly	Biannually
Medium (2 < TTR < 5 yrs)	Quarterly	Biannually	Biannually
Far (TTR > 5 yrs)	Biannually	Biannually	Annually
TTR: time to receptor (distance to receptor/seepage velocity)			

DURATION

MAROS uses a simple decision matrix to indicate the duration of future groundwater monitoring at the site to be sufficient prior to determination of site closure. Users can compare the projected duration of the sampling at their site to the suggested duration of monitoring evaluated based on the decision matrix below. If their site has groundwater monitoring planned for a significantly longer time period, then some reduction in the monitoring duration could be applied, subject to local and federal regulations.

The sampling duration at the site is determined by the Monitoring System Category assigned by the results from the Source and Tail Stability as well as the length of the sampling record available. Sites with both decreasing Source and Tail Results are suggested to end the sampling. Sites with Source or Tail results that indicate an increasing plume size are recommended for indefinite sampling.

TABLE A.5.3 DURATION DETERMINATION FOR SITES WITH NO CURRENT SITE TREATMENT.

Sampling Record	Monitoring System Category	
	S Trends	D Trends
Small (< 2 yrs)	6 more years	3 more years
Medium (2 < TTR < 10 yrs)	4 more years	2 more years
Large (> 10 yrs)	2 more years	1 more year
S Trends (Stable or No Trend); D Trends (Decreasing or Probably Decreasing)		

SAMPLING DENSITY

MAROS uses a simple rule of thumb to indicate how many wells at the site may be sufficient for groundwater monitoring. Users can compare the number of wells at their site to the number of wells from the rule of thumb. If their site has significantly more wells being sampled, then some reduction in the number of wells is possible. Note that users can use the sampling optimization (Sample Location) wing of the software to perform a more rigorous analysis of the number of wells required for monitoring.

The simple rule of thumb is based on two large databases of historical plume data were considered when evaluating the minimum well density reflecting both BTEX and chlorinated solvent plume information (Mace, 1997 and McNab, 1999). Mace (1997) used data from 138 BTEX plumes while McNab (1999) presented data from 37 the chlorinated solvent plumes. These data were combined, plotted, and then used to develop the following equation:

$$\text{sampling density (number of wells)} = 1.5(plumelength)^{0.4}$$

= where plume length is in units of feet and the sampling density is the number of wells for the entire plume.

In other words, this equation indicates the monitoring well density actually in use at the sites in the database and is based on plumes of different sizes (roughly 50 ft to 5000 ft).

MAROS uses this equation to indicate a well density that is typical at many sites. Based on recommendations developed by ASTM (1998), a minimum of four wells is specified for all plumes. User should also consider the well density in light of adequately defining/characterizing the plume through gathering sufficient site information.

Current Site Treatment

Sites currently undergoing site treatment (i.e. pump and treat system, etc.) have separate site suggestions for sampling frequency, duration and density applied.

FREQUENCY

No recommendation is given for the sampling frequency at a site that is currently undergoing remediation.

DURATION

MAROS applies the rules indicated below to assess the duration of future groundwater monitoring at the site to be sufficient prior to determination of site closure. Users can compare the projected duration of the sampling at their site to the suggested duration of monitoring evaluated based on the algorithm below. If their site has groundwater monitoring planned for a significantly longer time period, then some reduction in the monitoring duration could be applied, subject to local and federal regulations.

The sampling duration at the site is determined by the Source and Tail Stability results. Sites with both decreasing Source and Tail trends are suggested to continue remediation mechanism until reach stable trend or PRG met. Sites with Source or Tail results that indicate an increasing plume size are recommended for indefinite remediation or consider increasing performance or remediation mechanism. Sites with Stable or No Trend in the Source and Tail suggest to remove treatment system if previously reducing concentration or PRG met.

SAMPLING DENSITY

The sampling density determination for a site currently undergoing remediation is identical to that not currently undergoing site treatment. However, the results should be considered in the context of evaluating both regulatory compliance as well as remediation method performance evaluation.

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APPENDIX A.6 — IMPORT FILE FORMATS

Excel Format

The following format for Microsoft Excel Files (Table A.6.1) should be used for importing files into MAROS from Excel. The Constituent Naming convention follows ERPIMS. The Excel template file "MAROS_ExcelTemplate.xls" should be used to create an import file for the MAROS software. Each row in the import file should be one value for a COC, date and Well. Do not enter spike matrices or blanks. Use the Constituent list found in the "MAROS_ConstituentList.xls" file for naming conventions (contains about 2,100 constituents). Example names for common constituents can be found in Table A.6.6.

TABLE A.6.1 REQUIRED FIELD FORMAT FOR EXCEL IMPORT FILES: SAMPLING RESULTS

Column Number	Field Name	Description
1	WellName	Name of the groundwater well sampled, be sure all wells are "spelled" the same.
2	XCoord	X coordinate of the well, although not mandatory, it is suggested that you enter this field, for graphing purposes
3	YCoord	Y coordinate of the well, although not mandatory, it is suggested that you enter this field, for graphing purposes
4	Constituent	Compound measured - mandatory entry: Follow the ERPIMS format of the naming convention found in the Excel template file (included with software).
5	SampleDate	Date Sample was collected: format mm/dd/yyyy
6	Result	Analytical result: enter result as a number, if non-detect then leave blank
7	Units	Measurement units for result: choices mg/L; ug/L; ng/L; g/L; pg/L
8	DetLim	Reporting Limit (detection limit) - same units as "Result"
9	Flags	Flag "ND" for non-detect (must enter the detection limit), or "TR" for trace amount (must enter both detection limit and the result)

ERPIMS Format

The following format for ERPIMS files in Microsoft Access (Table A.6.2-5) or ERPIMS text files should be used for importing files into MAROS. The Constituent Naming convention follows ERPIMS. The Access template file "MAROS_AccessTemplate.mdb" should be followed to import an ERPIMS Access import file for the MAROS software. Only the fields with an asterix (*) below are mandatory fields for the ERPIMS **Access** import file.

TABLE A.6.2 REQUIRED FIELD FORMAT FOR LDI IMPORT FILES: LOCATION RESULTS

Column Number	Field Name	Description
1	**AFIID**	* Air Force Installation
2	**LOCID**	* Location Identifier
3	LTCODE	Location Classification Code
4	LPRCODE	Location Proximity Code
5	**NCOORD**	* North State Plane Coordinate
6	**ECOORD**	* East State Plane Coordinate
7	**CRDTYPE**	* Coordinate System Type
8	CRDMETH	Coordinate System Method
9	CRDUHN	Precision of the Coordinates
10	**CRDUNITS**	* Coordinates Units of Measure
11	ESTDATE	Date Established
12	ESCCODE	Establishing Company Code
13	DRLCODE	Drilling Company Code
14	EXCCODE	Excavating Company Code
15	CMCCODE	Construction Method Code
16	ELEV	Surface Elevation
17	ELEVMETH	Elevation Determination Method
18	ELEVUN	Precision of the Elevation
19	ELEVUNITS	Elevation Units of Measure
20	ELFLAG	More Current Elevation Available in
21	WINTDEPTH	Borehole Depth
22	BHDIAM	Borehole Diameter
23	BHANGLE	Angle of Borehole Drilling
24	BHAZIM	Azimuth of Borehole Drilling
25	DATUM	Geodetic Datum Identifier
26	STPZONE	Coordinate Zone for Geodetic Datum attribute
27	STPPROJ	Geographic Projection
28	UTMZONE	Unit of Coordinate Zone for Geodetic Datum attribute
29	GEOLOG	References Drilling Logs
30	MAPID	Map Identifier
31	LOCDESC	Location Description

TABLE A.6.3 REQUIRED FIELD FORMAT FOR TES IMPORT FILES: TESTING RESULTS

Column Number	Field Name	Description
1	**SAMPLESEQ**	* Sample Sequence Number
2	**TESTSEQ**	* Test Sequence Number
3	LABCODE	Laboratory Company Code
4	ANMCODE	Analytical Method Code
5	EXMCODE	Extraction Method Code
6	RUN_NUMBER	Run Number
7	LABSAMPID	Laboratory Sample Identification
8	LABRECDATE	Date/time of Reception by Lab
9	LABRECTEMP	Sample Temperature at Reception
10	LABRECUNITS	Celsius or Fahrenheit
11	EXTDATE	Date/time of Extraction
12	LCHDATE	Date/time of Leaching
13	LCHMETH	Method of Leaching
14	LCHLOT	Designator of a Group of Samples Leachated Together
15	ANADATE	Date/time of Analysis
16	ANALOT	Designator of a Group of Samples Analyzed Together
17	LABLOTCTL	Laboratory Lot Control Number
18	LABLOT_SEQ	Sequence Number of Lab Lot
19	CALREFID	Reference Link Between Samples and Corresponding Calibration
20	RTTYPE	Remediation Technology Type
21	BASIS	Basis

TABLE A.6.4 REQUIRED FIELD FORMAT FOR SAM IMPORT FILES: SAMPLE RESULTS

Column Number	Field Name	Description
1	**SAMPLESEQ**	* Sample Sequence Number
2	**AFIID**	* Air Force Installation
3	CONTRACTSEQ	Contract Sequence Number
4	**LOCID**	* Location Identifier
5	**LOGDATE**	* Log Date (Note: the time of sampling should NOT be included)
6	**MATRIX**	* Sampling Matrix
7	SBD	Sample Beginning Depth
8	SED	Sample Ending Depth
9	**SACODE**	* Sample Type Code
10	**SAMPNO**	* Sample Number
11	LOGCODE	Logging Company Code
12	SMCODE	Sampling Method Code
13	WETCODE	Moisture Content
14	**FLDSAMPID**	* Field Sample Identifier
15	COOLER	Cooler Identifier
16	COCID	Chain of Custody Identifier
17	ABLOT	Ambient Blank Identifier
18	EBLOT	Equipment Blank Identifier
19	TBLOT	Trip Blank Identifier
20	SAPROG	Program Authorization
21	REMARKS	Comments About the Sample

TABLE A.6.5 REQUIRED FIELD FORMAT FOR RES IMPORT FILES: RESULTS

Column Number	Field Name	Description
1	**TESTSEQ**	* Tests Sequence Number
2	**RESULTSEQ**	* Results Sequence Number
3	**PARLABEL**	* Parameter Label
4	**PRCCODE**	* Parameter Classification Code
5	**PARVQ**	* Parameter Value Qualifier
6	**PARVAL**	* Parameter Value
7	PARUN	Parameter Value Uncertainty
8	PRESICION	Parameter Value Precision
9	EXPECTED	Expected Parameter Value
10	EVEXP	Integer Value of Expected Value
11	EVMAN	Decimal Value of Expected Value
12	EVPREC	Precision of Expected Value
13	**MDL**	* Method Detection Limit
14	**RL**	* AFCEE Reporting Limit
15	**UNITS**	* Units of Measure
16	VQ_1C	1st Column Value Qualifier
17	VAL_1C	1st Column Value
18	FCVALEXP	1st Column Value Integer Value
19	FCVALMAN	1st Column Value Decimal Value
20	FCVALPREC	Precision of 1st Column Value
21	VQ_CONFIRM	1st Column Value Qualifier
22	VAL_CONFIRM	Confirm Column Value
23	CNFVALEXP	Confirming Value Integer Value
24	CNFVALMAN	Confirming Value Decimal Value
25	CNFVALPREC	Precision of Confirming Value
26	DILUTION	Dilution Value
27	DILEXP	Dilution Value Integer Value
28	DILMAN	Dilution Value Decimal Value
29	DILPREC	Precision of Dilution Value
30	UNCVALEXP	Uncorrected Value Integer Value
31	UNCVALMAN	Uncorrected Value Decimal Value
32	CRVALEXP	Corrected Value Integer Value
33	CRVALMAN	Corrected Value Decimal Value
34	DQTYPE	Data Qualifier Type
35	**EPA_FLAGS**	* EPA Data Qualifier Codes

TABLE A.6.6 EXAMPLE MAROS CONSTITUENT NAME CONVENTION

CAS Number	Constituent	Abreviation or Synonym	ERPIMS Code	MAROS Constituent Name	Constituent Type
BTEX AND MTBE					
71-43-2	Benzene	B	BZ	BENZENE	ORG
100-41-4	Ethylbenzene	E	EBZ	ETHYLBENZENE	ORG
108-88-3	Toluene	T	BZME	TOLUENE	ORG
1330-20-7	Xylene (mixed isomers)	X	XYLENES	XYLENES, TOTAL	ORG
108-30-3	Xylene, m-	X	XYLENES1213	XYLENES, o & m	ORG
95-47-6	Xylene, o-	X	XYLENES1213	XYLENES, o & m	ORG
1634-04-4	Methyl t-Butyl Ether	MTBE	TBUTMEE	tert-BUTYL METHYL ETHER	ORG
CHLORINATED COMPOUNDS					
75-27-4	Bromodichloromethane		BDCME	BROMODICHLOROMETHANE	ORG
56-23-5	Carbon tetrachloride	CT	CTCL	CARBON TETRACHLORIDE	ORG
108-90-7	Chlorobenzene		CLBZ	CHLOROBENZENE	ORG
75-00-3	Chloroethane		CLEA	CHLOROETHANE	ORG
67-66-3	Chloroform	Trichloromethane	TCLME	CHLOROFORM	ORG
74-87-3	Chloromethane	Methyl Chloride	CLME	CHLOROMETHANE	ORG
95-57-8	Chlorophenol, 2-		CLPH2	2-CHLOROPHENOL	ORG
124-48-1	Dibromochloromethane		DBCME	DIBROMOCHLOROMETHANE	ORG
95-50-1	Dichlorobenzene (1,2) (-o)		DCBZ12	1,2-DICHLOROBENZENE	ORG
106-46-7	Dichlorobenzene, (1,4) (-p)		DCBZ14	1,4-DICHLOROBENZENE	ORG
75-71-8	Dichlorodifluoromethane		FC12	DICHLORODIFLUOROMETHANE	ORG
75-34-3	Dichloroethane, 1,1-	1,1 DCA	DCA11	1,1-DICHLOROETHANE	ORG
107-06-2	Dichloroethane, 1,2-	1, 2 DCA, EDC	DCA12	1,2-DICHLOROETHANE	ORG
156-59-2	Dichloroethene, cis-1,2-	1,2 cis DCE	DCE12C	cis-1,2-DICHLOROETHYLENE	ORG
156-60-5	Dichloroethene,1,2-trans-	1,2 trans DCE	DCE12T	trans-1,2-DICHLOROETHENE	ORG
75-09-2	Methylene chloride	Dichloromethane	MTLNCL	METHYLENE CHLORIDE	ORG
79-34-5	Tetrachloroethane, 1,1,2,2-		PCA	1,1,2,2-TETRACHLOROETHANE	ORG
127-18-4	Tetrachloroethene	PCE, Perc	PCE	TETRACHLOROETHYLENE(PCE)	ORG
120-82-1	Trichlorobenzene, 1,2,4-		TCB124	1,2,4-TRICHLOROBENZENE	ORG
71-55-6	Trichloroethane, 1,1,1-		TCA111	1,1,1-TRICHLOROETHANE	ORG
79-00-5	Trichloroethane, 1,1,2-	TCA	TCA112	1,1,2-TRICHLOROETHANE	ORG
79-01-6	Trichloroethene	TCE	TCE	TRICHLOROETHYLENE (TCE)	ORG
75-69-4	Trichlorofluoromethane		FC11	TRICHLOROFLUOROMETHANE	ORG
75-01-4	Vinyl chloride	VC	VC	VINYL CHLORIDE	ORG
PAH COMPOUNDS					
83-32-9	Acenaphthene		ACNP	ACENAPHTHENE	ORG
208-96-8	Acenaphthylene		ACNPY	ACENAPHTHYLENE	ORG
120-12-7	Anthracene		ANTH	ANTHRACENE	ORG
205-99-2	Benzo (b)Fluoranthene		BZBF	BENZO(b)FLUORANTHENE	ORG

CAS Number	Constituent	Abreviation or Synonym	ERPIMS Code	MAROS Constituent Name	Constituent Type
191-24-2	Benzo (g,h,i)Perylene		BZGHIP	BENZO(g,h,i)PERYLENE	ORG
207-08-9	Benzo (k) Fluoranthene		BZKF	BENZO(k)FLUORANTHENE	ORG
56-55-3	Benzo(a)Anthracene		BZAA	BENZO(a)ANTHRACENE	ORG
50-32-8	Benzo(a)Pyrene		BZAP	BENZO(a)PYRENE	ORG
218-01-9	Chrysene		CHRYSENE	CHRYSENE	ORG
53-70-3	Dibenzo(a,h) Anthracene		DBAHA	DIBENZ(a,h)ANTHRACENE	ORG
206-44-0	Fluoranthene		FLA	FLUORANTHENE	ORG
86-73-7	Fluorene		FL	FLUORENE	ORG
193-39-5	Indeno(1,2,3,c,d)Pyrene		INP123	INDENO(1,2,3-c,d)PYRENE	ORG
91-20-3	Naphthalene		NAPH	NAPHTHALENE	ORG
85-01-8	Phenanthrene		PHAN	PHENANTHRENE	ORG
129-00-0	Pyrene		PYR	PYRENE	ORG
OTHER COMPOUNDS					
67-64-1	Acetone		ACE	ACETONE	ORG
65-85-0	Benzoic acid		BZACID	BENZOIC ACID	ORG
71-36-3	Butanol, n-		BTOH	n-BUTANOL	ORG
75-15-0	Carbon disulfide		CDS	CARBON DISULFIDE	ORG
107-21-1	Ethylene glycol		ETEGLY	ETHYLENE GLYCOL	ORG
110-54-3	Hexane, n-		C6N	n-HEXANE	ORG
67-56-1	Methanol		MEOH	METHANOL	ORG
78-93-3	Methyl ethyl ketone	MEK	MEK	METHYL ETHYL KETONE (2-BUTANONE)	ORG
108-95-2	Phenol		PHENOL	PHENOL	ORG

APPENDIX A.7 — SAMPLE REPORTS

1. COC Assessment
2. Linear Regression Statistics
3. Mann-Kendall Statistics
4. Line of Evidence Summary
5. Site Results
6. Sampling Location Optimization Results
7. Sampling Frequency Optimization Results

MAROS COC Assessment

Project: Sample Site 1 **User Name:**

Location: Boston **State:** Massachusetts

Toxicity:

Contaminant of Concern	Representative Concentration (mg/L)	PRG (mg/L)	Percent Above PRG
LEAD	1.1E+01	1.5E-02	71554.9%
BENZENE	1.5E-01	5.0E-03	2817.6%
1,1,1,2-TETRACHLOROETHANE	4.1E-01	1.1E-01	270.9%
TOLUENE	1.8E+00	1.0E+00	84.6%
1,2-DICHLOROBENZENE	9.8E-01	6.0E-01	63.7%
COPPER	1.8E+00	1.3E+00	42.0%
BARIUM	3.2E+00	2.3E+00	37.7%
PERCHLORATE	1.2E-01	9.2E-02	35.6%

Note: Top COCs by toxicity were determined by examining a representative concentration for each compound over the entire site. The compound representative concentrations are then compared with the chosen PRG for that compound, with the percentage excedence from the PRG determining the compound's toxicity. All compounds above exceed the PRG.

Prevalence:

Contaminant of Concern	Class	Total Wells	Total Excedences	Percent Excedences	Total detects
LEAD	MET	11	9	81.8%	9
BENZENE	ORG	11	7	63.6%	9
BARIUM	MET	11	6	54.5%	11
TOLUENE	ORG	11	5	45.5%	11
COPPER	MET	11	4	36.4%	11
1,2-DICHLOROBENZENE	ORG	11	3	27.3%	11
1,1,1,2-TETRACHLOROETHANE	ORG	11	3	27.3%	8
PERCHLORATE	INO	11	2	18.2%	9

Note: Top COCs by prevalence were determined by examining a representative concentration for each well location at the site. The total excedences (values above the chosen PRGs) are compared to the total number of wells to determine the prevalence of the compound.

Mobility:

Contaminant of Concern	Kd
PERCHLORATE	
BENZENE	0.0984
TOLUENE	0.347
1,1,1,2-TETRACHLOROETHANE	0.857
1,2-DICHLOROBENZENE	1.91
LEAD	10
BARIUM	11
COPPER	40

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Note: Top COCs by mobility were determined by examining each detected compound in the dataset and comparing their mobilities (Koc's for organics, assume foc = 0.001, and Kd's for metals).

Contaminants of Concern (COC's)

BENZENE

ETHYLBENZENE

TOLUENE

XYLENES, TOTAL

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MAROS Linear Regression Statistics

Project: Sample Site 1 **User Name:**

Location: Boston **State:** Massachusetts

Constituent	Well	Source/ Tail	Average	Standard Deviation	Ln Slope	Coefficient of Variation	Confidence in Trend	Concentration Trend
BENZENE								
	MW-15	S	5.0E-04	0.0E+00	0.0E+00	0.0E+00	100.0%	S
	MW-13	S	1.7E-02	1.9E-02	-1.5E-03	1.1E+00	100.0%	D
	MW-1	S	3.6E-01	6.0E-01	-1.4E-03	1.7E+00	100.0%	D
	MW-14	S	9.5E-03	1.5E-02	-1.0E-03	1.6E+00	100.0%	D
	MW-4	T	6.9E-02	9.1E-02	-8.2E-04	1.3E+00	100.0%	D
	MW-5	T	1.1E+00	9.0E-01	-7.3E-04	8.5E-01	100.0%	D
	MW-6	T	5.0E-04	0.0E+00	0.0E+00	0.0E+00	100.0%	S
	MW-2	T	2.3E-02	7.4E-02	-5.8E-04	3.3E+00	100.0%	D
	MW-3	T	6.9E-02	7.3E-02	-1.3E-03	1.0E+00	100.0%	D
	MW-7	T	5.4E-04	1.3E-04	-3.1E-05	2.5E-01	100.0%	D
	MW-8	T	6.8E-04	6.7E-04	-9.5E-05	9.8E-01	100.0%	D
ETHYLBENZENE								
	MW-14	S	2.6E-03	3.6E-03	2.1E-04	1.4E+00	77.0%	NT
	MW-13	S	4.0E-02	1.3E-01	-5.0E-04	3.2E+00	100.0%	D
	MW-1	S	1.1E-01	1.1E-01	-1.1E-03	9.8E-01	100.0%	D
	MW-15	S	5.0E-04	0.0E+00	0.0E+00	0.0E+00	100.0%	S
	MW-4	T	3.7E-02	9.5E-02	-6.6E-04	2.6E+00	100.0%	D
	MW-2	T	4.0E-02	1.2E-01	-2.5E-04	3.0E+00	100.0%	D
	MW-3	T	1.7E-01	2.7E-01	-2.2E-03	1.6E+00	100.0%	D
	MW-6	T	5.0E-04	0.0E+00	0.0E+00	0.0E+00	100.0%	S
	MW-7	T	2.3E-03	6.8E-03	-1.8E-04	2.9E+00	100.0%	D
	MW-5	T	4.0E+00	5.6E+00	-2.0E-03	1.4E+00	100.0%	D
	MW-8	T	7.9E-04	7.5E-04	-1.5E-04	9.6E-01	100.0%	D
TOLUENE								
	MW-14	S	5.1E-01	3.8E-01	7.4E-04	7.4E-01	99.7%	I
	MW-15	S	3.7E+00	1.3E+00	-8.2E-05	3.6E-01	100.0%	D
	MW-13	S	2.9E-01	3.6E-01	1.5E-03	1.2E+00	99.9%	I
	MW-1	S	8.9E-03	1.2E-02	-7.7E-06	1.3E+00	100.0%	D
	MW-6	T	6.4E+00	1.3E+00	4.2E-05	2.1E-01	80.5%	NT
	MW-5	T	4.3E-03	6.8E-03	3.7E-04	1.6E+00	79.5%	NT
	MW-4	T	4.5E-02	4.2E-02	-1.2E-04	9.2E-01	100.0%	D
	MW-7	T	2.7E+00	7.0E-01	4.5E-05	2.6E-01	78.8%	NT
	MW-3	T	1.4E-02	2.8E-02	-4.2E-04	2.0E+00	100.0%	D
	MW-8	T	5.6E+00	8.6E-01	-5.2E-05	1.6E-01	100.0%	D
	MW-2	T	1.1E+00	7.0E-01	3.1E-04	6.5E-01	93.3%	PI
XYLENES, TOTAL								
	MW-1	S	2.0E+00	2.2E+00	-9.8E-04	1.1E+00	100.0%	D
	MW-13	S	8.3E-02	1.9E-01	-1.9E-03	2.3E+00	100.0%	D
	MW-14	S	4.6E-02	7.9E-02	-1.1E-03	1.7E+00	100.0%	D
	MW-15	S	5.0E-04	0.0E+00	0.0E+00	0.0E+00	100.0%	S
	MW-5	T	8.8E+00	8.3E+00	-9.6E-04	9.4E-01	100.0%	D

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Project: Sample Site 1 **User Name:**

Location: Boston **State:** Massachusetts

Constituent	Well	Source/ Tail	Average	Standard Deviation	Ln Slope	Coefficient of Variation	Confidence in Trend	Concentration Trend
XYLENES, TOTAL								
	MW-7	T	3.0E-03	9.2E-03	-1.9E-04	3.1E+00	100.0%	D
	MW-2	T	2.6E-02	8.0E-02	-6.2E-04	3.1E+00	100.0%	D
	MW-8	T	5.0E-04	0.0E+00	0.0E+00	0.0E+00	100.0%	S
	MW-3	T	5.6E+00	6.6E+00	-2.0E-03	1.2E+00	100.0%	D
	MW-4	T	2.2E-01	5.4E-01	-3.9E-04	2.5E+00	100.0%	D
	MW-6	T	5.0E-04	0.0E+00	0.0E+00	0.0E+00	100.0%	S

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MAROS Mann-Kendall Statistics

Project: Sample Site 1 **User Name:**

Location: Boston **State:** Massachusetts

	Well	Source/ Tail	Coefficient of Variation	Mann-Kendall Statistic	Confidence in Trend	Concentration Trend
BENZENE						
	MW-15	S	0.0E+00	0	42.3%	S
	MW-13	S	1.1E+00	-53	99.8%	D
	MW-1	S	1.7E+00	-15	98.5%	D
	MW-14	S	1.6E+00	-50	99.9%	D
	MW-4	T	1.3E+00	-57	99.8%	D
	MW-5	T	8.5E-01	-31	99.8%	D
	MW-6	T	4.5E-16	0	47.8%	S
	MW-2	T	3.3E+00	-24	91.8%	PD
	MW-3	T	1.0E+00	-69	100.0%	D
	MW-7	T	2.5E-01	-7	62.6%	S
	MW-8	T	9.8E-01	-11	70.5%	S
ETHYLBENZENE						
	MW-14	S	1.4E+00	7	63.9%	NT
	MW-13	S	3.2E+00	-17	80.6%	NT
	MW-1	S	9.8E-01	-11	93.2%	PD
	MW-15	S	0.0E+00	0	42.3%	S
	MW-4	T	2.6E+00	-29	91.6%	PD
	MW-2	T	3.0E+00	-7	63.9%	NT
	MW-3	T	1.6E+00	-85	100.0%	D
	MW-6	T	4.5E-16	0	47.8%	S
	MW-7	T	2.9E+00	-7	62.6%	NT
	MW-5	T	1.4E+00	-33	99.9%	D
	MW-8	T	9.6E-01	-15	77.5%	S
TOLUENE						
	MW-14	S	7.4E-01	57	100.0%	I
	MW-15	S	3.6E-01	-4	70.3%	S
	MW-13	S	1.2E+00	71	100.0%	I
	MW-1	S	1.3E+00	3	61.4%	NT
	MW-6	T	2.1E-01	11	70.5%	NT
	MW-5	T	1.6E+00	11	81.0%	NT
	MW-4	T	9.2E-01	-1	50.0%	S
	MW-7	T	2.6E-01	12	72.3%	NT
	MW-3	T	2.0E+00	-8	63.3%	NT
	MW-8	T	1.6E-01	-24	89.3%	S
	MW-2	T	6.5E-01	26	93.6%	PI
XYLENES, TOTAL						
	MW-1	S	1.1E+00	-11	93.2%	PD
	MW-13	S	2.3E+00	-65	100.0%	D
	MW-14	S	1.7E+00	-63	100.0%	D

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Project: Sample Site 1 **User Name:**

Location: Boston **State:** Massachusetts

Well	Source/ Tail	Coefficient of Variation	Mann-Kendall Statistic	Confidence in Trend	Concentration Trend
XYLENES, TOTAL					
MW-15	S	0.0E+00	0	42.3%	S
MW-5	T	9.4E-01	-37	100.0%	D
MW-7	T	3.1E+00	-7	62.6%	NT
MW-2	T	3.1E+00	-14	78.2%	NT
MW-8	T	4.5E-16	0	47.8%	S
MW-3	T	1.2E+00	-83	100.0%	D
MW-4	T	2.5E+00	-17	78.2%	NT
MW-6	T	4.5E-16	0	47.8%	S

Note: Increasing (I); Probably Increasing (PI); Stable (S); Probably Decreasing (PD); Decreasing (D); No Trend (NT); Not Applicable (N/A); Source/Tail (S/T)

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MAROS Lines of Evidence Summary

Project: Sample Site 1 **User Name:**

Location: Boston **State:** Massachusetts

Constituent	Well	Source/ Tail	Mann-Kendall	Linear Regression	Modeling	Empirical
BENZENE						
	MW-15	S	S	S	S	N/A
	MW-13	S	D	D	S	N/A
	MW-1	S	D	D	S	N/A
	MW-14	S	D	D	S	N/A
	MW-4	T	D	D	S	N/A
	MW-5	T	D	D	S	N/A
	MW-6	T	S	S	S	N/A
	MW-2	T	PD	D	S	N/A
	MW-3	T	D	D	S	N/A
	MW-7	T	S	D	S	N/A
	MW-8	T	S	D	S	N/A
ETHYLBENZENE						
	MW-14	S	NT	NT	S	N/A
	MW-13	S	NT	D	S	N/A
	MW-1	S	PD	D	S	N/A
	MW-15	S	S	S	S	N/A
	MW-4	T	PD	D	S	N/A
	MW-2	T	NT	D	S	N/A
	MW-3	T	D	D	S	N/A
	MW-6	T	S	S	S	N/A
	MW-7	T	NT	D	S	N/A
	MW-5	T	D	D	S	N/A
	MW-8	T	S	D	S	N/A
TOLUENE						
	MW-14	S	I	I	S	N/A
	MW-15	S	S	D	S	N/A
	MW-13	S	I	I	S	N/A
	MW-1	S	NT	D	S	N/A
	MW-6	T	NT	NT	S	N/A
	MW-5	T	NT	NT	S	N/A
	MW-4	T	S	D	S	N/A
	MW-7	T	NT	NT	S	N/A
	MW-3	T	NT	D	S	N/A
	MW-8	T	S	D	S	N/A
	MW-2	T	PI	PI	S	N/A
XYLENES, TOTAL						
	MW-1	S	PD	D	S	N/A
	MW-13	S	D	D	S	N/A
	MW-14	S	D	D	S	N/A
	MW-15	S	S	S	S	N/A
	MW-5	T	D	D	S	N/A

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Project: Sample Site 1 **User Name:**

Location: Boston **State:** Massachusetts

Constituent	Well	Source/ Tail	Mann-Kendall	Linear Regression	Modeling	Empirical
XYLENES, TOTAL						
	MW-7	T	NT	D	S	N/A
	MW-2	T	NT	D	S	N/A
	MW-8	T	S	S	S	N/A
	MW-3	T	D	D	S	N/A
	MW-4	T	NT	D	S	N/A
	MW-6	T	S	S	S	N/A

Note: Increasing (I); Probably Increasing (PI); Stable (S); Probably Decreasing (PD); Decreasing (D); No Trend (NT); Not Applicable (N/A); Source/Tail (S/T)

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MAROS Site Results

Project: Sample Site 1 **User Name:**

Location: Boston **State:** Massachusetts

Recommendation Basis:

Monitoring System Category from Compliance Monitoring Analysis Moderate

Number of Source Wells: 4 **Number of Tail Wells:** 7

Hydrogeology and Plume Information:

Main Constituents: BTEX

Groundwater Seepage Velocity: 92 ft/yr

Current Plume Length: 200 ft

Current Plume Width: 30 ft

Source Information:

Source Treatment: No Current Site Treatment

NAPL is not present at this site.

Down-gradient Information:

Distance from Source to Nearest:

Down-gradient receptor: 1200 ft

Down-gradient property: 1200 ft

Distance from Edge of Tail to Nearest:

Down-gradient receptor: 1000 ft

Down-gradient property: 1000 ft

Compliance Monitoring/Remediation Optimization Results:

Preliminary Monitoring System Optimization Results: Based on site classification, source treatment and Monitoring System Category the following suggestions are made for site Sampling Frequency, Duration of Sampling, and Well Density. These criteria take into consideration: Plume Stability, Type of Plume, and Groundwater Velocity.

COC	Tail Stability	Source Stability	Design Category	Sampling Duration	Sampling Frequency	Sampling Density
BENZENE	PD	D	L	Sample 1 more year	Biannually (6 months)	13
ETHYLBENZENE	PD	S	L	Sample 2 more years	Biannually (6 months)	13
TOLUENE	S	NT	M	Sample 2 more years	Biannually (6 months)	13
XYLENES, TOTAL	PD	PD	L	Sample 1 more year	Biannually (6 months)	13

Note:

Plume Status: (I) Increasing; (PI)Probably Increasing; (S) Stable; (NT) No Trend; (PD) Probably Decreasing; (D) Decreasing

Design Categories: (E) Extensive; (M) Moderate; (L) Limited (N/A) Not Applicable, Insufficient Data Available

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MAROS Sampling Location Optimization Results

Project: Sample Site 1 **User Name:**

Location: Boston **State:** Massachusetts

Analysis by DeLauney Method

Sampling Events Analyzed: **From** Sample Event 13 12/10/97

To Sample Event 15 12/19/98

Constituent	Well Name	Average Slope Factor	Eliminated?
BENZENE	MW-8	0.747	☐
	MW-13	0.185	☑
	MW-14	0.199	☐
	MW-15	0.588	☐
	MW-2	0.450	☐
	MW-3	0.350	☑
	MW-4	0.270	☑
	MW-5	0.590	☐
	MW-6	0.664	☐
	MW-7	0.532	☐
	MW-1	0.460	☐
ETHYLBENZENE	MW-6	0.557	☐
	MW-5	0.490	☐
	MW-4	0.371	☐
	MW-3	0.413	☐
	MW-2	0.389	☐
	MW-15	0.509	☐
	MW-14	0.287	☐
	MW-7	0.390	☐
	MW-1	0.513	☐
	MW-8	0.624	☐
	MW-13	0.295	☑
TOLUENE	MW-5	0.647	☐

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	MW-1	0.458	☐
	MW-6	0.483	☐
	MW-8	0.611	☐
	MW-4	0.341	☑
	MW-3	0.757	☐
	MW-2	0.454	☐
	MW-15	0.433	☐
	MW-14	0.119	☐
	MW-13	0.354	☑
	MW-7	0.182	☐
XYLENES, TOTAL	MW-3	0.474	☐
	MW-7	0.602	☐
	MW-6	0.743	☐
	MW-5	0.623	☐
	MW-4	0.554	☐
	MW-2	0.648	☐
	MW-15	0.658	☐
	MW-14	0.406	☐
	MW-1	0.515	☐
	MW-8	0.797	☐
	MW-13	0.481	☐

Note: The Delauney method results tell how important a well is in a given sampling event. The larger the SF value of a well, the more important it is.

Abandoned Sampling Locations by considering all COCs

Well Name	East Coord.	North Coord.	Abandoned?
MW-1	13.000	-20.000	☐
MW-13	65.000	23.000	☐
MW-14	102.000	20.000	☐
MW-15	190.000	-125.000	☐
MW-2	-2.000	30.000	☐
MW-3	35.000	10.000	☐

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Project: Sample Site 1 **User Name:**

Location: Boston **State:** Massachusetts

MW-4	55.000	-37.000	☐
MW-5	-4.000	-70.000	☐
MW-6	-77.000	5.000	☐
MW-7	-87.000	-75.000	☐
MW-8	-55.000	-95.000	☐

To be conservative, a location is abandoned only when it is eliminated from all COCs.

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MAROS Sampling Frequency Optimization Results

Project: Sample Site 1 **User Name:**

Location: Boston **State:** Massachusetts

Analysis by Modified CES Method

Number of Sampling Events Analyzed: 15

Recent Sampling Events: **From** Sample Event 4 5/31/90

To Sample Event 15 12/19/98

Constituent	Well Name	Sampling Frequency	Frequency based on current period	Frequency based on overall period
BENZENE	MW-1	Annual	Annual	Annual
	MW-13	Annual	Annual	Annual
	MW-14	Annual	Annual	Annual
	MW-15	Biennial	Annual	Annual
	MW-2	Annual	Annual	Annual
	MW-3	Annual	Annual	Annual
	MW-4	Annual	Annual	Annual
	MW-5	Annual	Annual	Annual
	MW-6	Biennial	Annual	Annual
	MW-7	Biennial	Annual	Annual
	MW-8	Biennial	Annual	Annual
ETHYLBENZENE	MW-1	Annual	Annual	Annual
	MW-13	Annual	Annual	Annual
	MW-14	Annual	Annual	Annual
	MW-15	Biennial	Annual	Annual
	MW-2	Annual	Annual	Annual
	MW-3	Biennial	Annual	Annual
	MW-4	Annual	Annual	Annual
	MW-5	Annual	Annual	Annual
	MW-6	Biennial	Annual	Annual
	MW-7	Annual	Annual	Annual
	MW-8	Annual	Annual	Annual

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TOLUENE	MW-1	Annual	Annual	Annual
	MW-13	Annual	Annual	Annual
	MW-14	Annual	Annual	Annual
	MW-15	Annual	Annual	Annual
	MW-2	Annual	Annual	Annual
	MW-3	Annual	Annual	Annual
	MW-4	Annual	Annual	Annual
	MW-5	Annual	Annual	Annual
	MW-6	Annual	Annual	Annual
	MW-7	Annual	Annual	Annual
	MW-8	Annual	Annual	Annual
XYLENES, TOTAL	MW-1	Annual	Annual	Annual
	MW-13	Biennial	Annual	Annual
	MW-14	Biennial	Annual	Annual
	MW-15	Biennial	Annual	Annual
	MW-2	Annual	Annual	Annual
	MW-3	Annual	Annual	Annual
	MW-4	Annual	Annual	Annual
	MW-5	Annual	Annual	Annual
	MW-6	Biennial	Annual	Annual
	MW-7	Annual	Annual	Annual
	MW-8	Biennial	Annual	Annual

Note:Modified CES (LLNL) method results in a recommended sampling interval for each well. This is based on analysis of concentration trend, so looks at specified sampling interval.

Summary - Final Recommendation for Sampling Frequency

Well Name	Sampling Frequency
MW-1	Annual
MW-13	Annual
MW-14	Annual
MW-15	Annual
MW-2	Annual
MW-3	Annual

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Project: Sample Site 1 **User Name:**

Location: Boston **State:** Massachusetts

MW-4	Annual
MW-5	Annual
MW-6	Annual
MW-7	Annual
MW-8	Annual

Note: the most stringent sampling frequency was chosen among all COCs.

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